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Energy status in Lebanon and electricity generation reform plan based on cost and pollution optimization

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ABSTRACT

This paper presents a review of the energy status, conventional and renewable, in Lebanon and illustrates their problems with the suggested recommendations. In addition, a detailed review of the principal directorates of the electricity of Lebanon Company (EDL) is also presented all along with the existing problems and recommended solutions. An economic, environmental optimization of different power sources is studied, where three scenarios are introduced based on the fuel source of different CCGT power plants. The results emphasized on the maximum possible use of wind energy and natural gas in electricity generation. Based on the optimization study, a five-year master plan for electricity generation is modeled. The suggested plan has an investment capital cost of 5553 M$ with the savings and additional incomes being 5900 M$ compared to EDL financial status in the adopted base year, 2009. In addition, this plan exceeds the trend to introduce a 12% share of renewable energy in the power sector by 2020, where the share is supposed to be about 15% out of the total installed capacity before this date. The concluding remarks highlight the role of politics in the development of the energy sector.

Contents

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1. Introduction

Lebanon is located on the Eastern edge of the Mediterranean Sea between the North Latitudes 33° 03′ 38″ and 34° 41′ 35″ and East Longitudes 35° 06′ 22″ and 36° 37′ 22″. Its area is about 10,452 km^2, and consists of a narrow coastal strip of land adjacent to the Mediterranean Sea. Its coastline is about 220 km long. The climate in Lebanon is Mediterranean; mild to cool with wet winters and hot, dry summers; with the temperature in the capital Beirut ranging from 5 °C in winter up to 36 °C in summer. The Lebanese Mountains experience heavy winter snows. The population is around 4 million and it has $4010 per capita GNI (Gross national income) [1]. The high population density and good standards of living reflect a relatively, large energy demand.

Lebanon meets nearly all its energy needs from the importation of oil products, because it currently lacks the conventional fossil fuel energy resources and is not effectively benefiting from the available renewable energy resources. In 2008, more than 5 million toe (tons of oil equivalent) were imported, of which 49% were consumed for electricity generation. In the same year, renewable energy shared only about 3.7% of the total primary energy supply (TPES) (Fig. 1(a)).

The total primary energy supply (TPES) in 2008, divides among the different sectors as shown in Fig. 1(b). In addition, a historical development of TPES between 1992 and 2010 is shown in Fig. 2.

Knowing that about 49% of oil imports are used for electricity production and taking into account the losses in the electricity system and some other transformations, the total amount of energy sources left for final consumption is about 3561 ktoe [2] and it is distributed as shown in Fig. 3(a). The total final energy consumption is divided among different sectors as shown in Fig. 3(b).

2. Conventional energy in Lebanon

2.1. Coal

The Lebanese energy market is principally based on oil derivatives. That is why coal is imported in minor quantities. It shares about 2.5% of the TPES and is mainly consumed by the two cement factories in Chikka and Siblin.

2.2. Oil sector

Lebanon has no known fossil fuel recourses until now. But it is located in an oil producing region and the neighboring bordering countries (Syria and Israel) benefit from important oil resources and thus, from the geological point of view, a high probability of finding such energy resources in Lebanon is present. Moreover, old tests, particularly in the Northern offshore area, have indicated positive results [5] and all seismic surveys carried out by US and European countries during the past few years proved the existence of oil on the offshore [6]. Recently, on January 4, 2012, the government succeeded to endorse the decrees related to oil and gas, which identify the administration of these resources off the Lebanese coast [6]. This is a good step that would solve a lot of the Lebanese socio-economic problems in case of success in finding some conventional energy resources. However, the question that obviously originates is: Why the prospect will be only offshore, knowing that old tests gave positive results onshore?

As for the petroleum market, importation and distribution are being conducted by several private companies, but the specifications and prices are fixed by MEW. The petroleum invoice has been continuously increasing over the past years reaching about 4000 million dollars in 2008 (Fig. 4). This fact imposes a serious financial trouble on a developing country that already suffers the problem of huge public debt.

Furthermore, the Lebanese government owns two old, non-operational refineries in Zahrani and Beddawi, which used to receive crude oil respectively from Saudi-Arabia and Iraq through two, closed-nowadays pipelines. These refineries are being used only as import terminals and storage facilities for refined oil products [8].

Lebanon imports six kinds of oil derivatives: fuel oil, diesel/gas oil, gasoline, kerosene, liquefied petroleum gas, and asphalt.

Nomenlature

AMR	Automatic meter reading
BOT	Built, operate, transfer
CAS	Central administration for statistics
CCGT/CC	Combined cycle gas turbine
CDM	Clean development mechanisms
CEDRO	Country energy efficiency and renewable energy demonstration project for the recovery of Lebanon
CF	Capacity factor
CFL	Compact fluorescent lamp
CHP	Combined heat and power
CoM	Council of Ministers
DO	Diesel oil
EE	Energy efficiency
EDF	Électricité de France
EDL	Electricity of Lebanon
ESCO	Energy service company
GB	Green buildings
GHG	Green house gas
GISELO	Geographic information systems electricity of Lebanon
GNI	Gross national income
GO	Gas oil
GoL	Government of Lebanon
GT	Gas turbine
HFO	Heavy fuel oil
HV	High voltage
IGCC	Integrated gasification combined cycle
IPP	Independent power producer
KPI	Key performance indicator
k.v.a.r.h	Kilo volt ampere reactive hour
LCEC	Lebanese Center for Energy Conservation
LEED	Leader ship in energy and environmental design
LENCC	Lebanese Electricity National Control Center
LL	Lebanese Lira
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
LSDP	Letter of Sectoral Development Policy
LV	Low voltage
MCM	Million cubic meters
MEW	Ministry of Energy and Water
MSW	Municipal solid wastes
MV	Medium voltage
NCV	Net calorific value
NEEREA	National Energy Efficiency and Renewable Energy Account
NEMA	National Electrical Manufacturers Association
NG	Natural gas
NGO	Non-governmental organization
NGV	Natural gas vehicle
OCGT	Open cycle gas turbine
O&M	Operating & Maintenance
ONL	National Office of Litani
PT	Parabolic trough
PV	Photovoltaic
RE	Renewable energy
SP	Service provision
ST	Steam turbine
SWHS	Solar water heating system
t	Time in years
tCO_{2eq}/MW h	Tons of CO_2 equivalent per MW h
toe	Tons of oil equivalent
TOU	Time of use
TPES	Total primary energy supply
TVA	Tax on the value added
UNDP	United Nations Development Program
US$	United States dollar
WT	Wind turbine

Fig. 5 shows, for each kind, the amount imported to Lebanon between 1995 and 2010 in order to fulfill its energy needs.

2.2.1. Fuel oil

Fuel oil has the second highest oil importation rate in Lebanon with 24% in 2010 after diesel which amounted to 40% [4]. Fuel oil is majorly used by the two thermal power plants in Jieh and Zouk Mikael, in addition to some small generators that serve their factories and industrial facilities [9].

2.2.2. Diesel oil

Diesel constitutes the major oil importation rate in Lebanon. The imported diesel is of low quantity, which exerts a heavy burden on the local environment and participates in mounting up the national health bill. It is used in transport, industry, heating and electricity generated by the four thermal power plants in Zahrani, Beddawi, Tyre, and Baalbek, in addition to that generated by back-up private generators that serve as a complement to the electricity produced by EDL [9].

2.2.3. Gasoline

Gasoline imports are mainly used in the transport sector. The government exerts high taxes on this imported product which is very essential and effective in the Lebanese daily life and this is generating great complaints by the Lebanese.

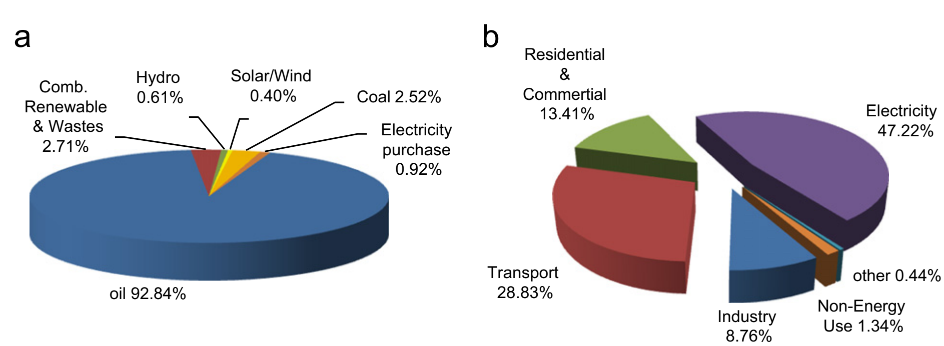

Fig. 1. (a) Primary energy supply in Lebanon in 2008 (data source: [2]), (b) TPES distribution by sectors in 2008 (data source: [2]).

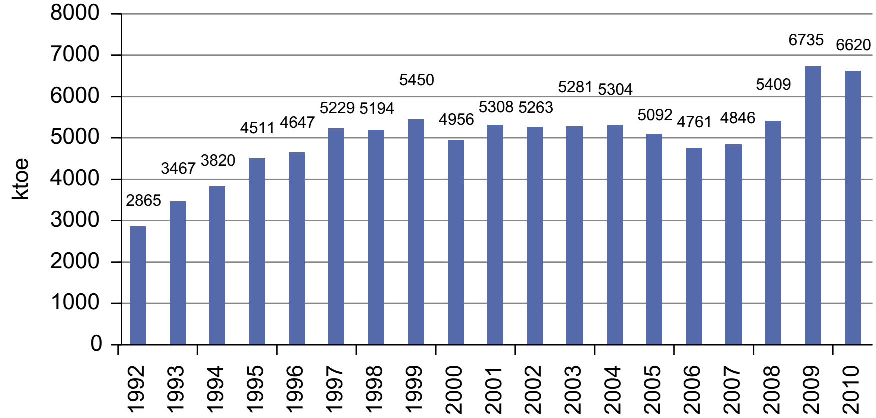

Fig. 2. Evolution of TPES between 1992 and 2010 (data source: [3] and [4]).

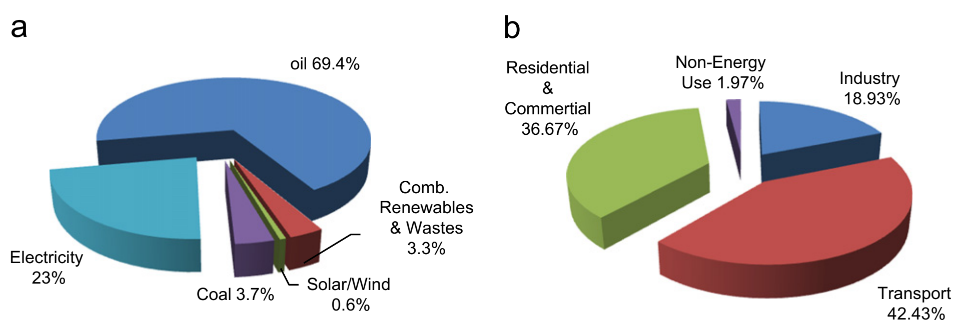

Fig. 3. (a) Distribution of total amount of energy sources left for final consumption in 2008 (data source: [2]), (b) distribution of final energy consumption (data source: [2]).

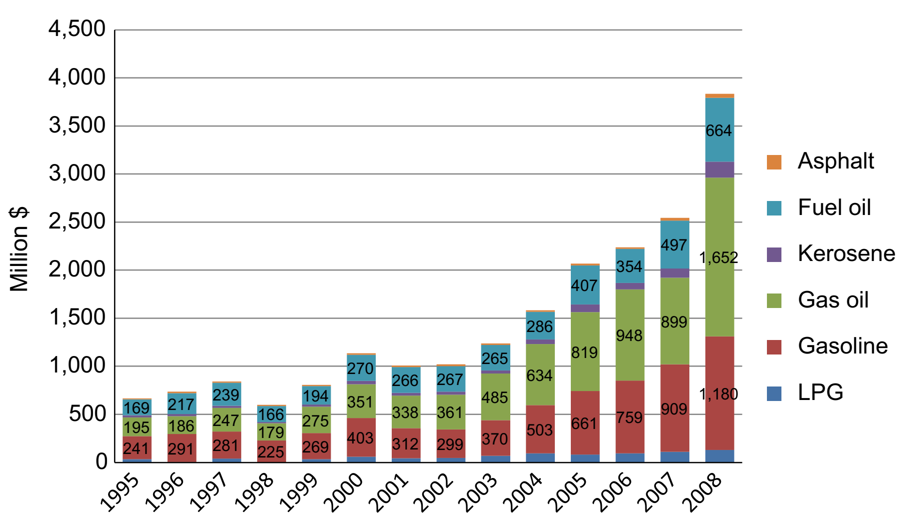

Fig. 4. Evolution of petroleum invoice between 1995 and 2008 (data source: [7]).

2.2.4. Liquefied petroleum gas (LPG)

Liquefied petroleum gas (LPG) shares a small percentage of the total oil importation. It is mainly used for domestic and commercial use.

2.2.5. Kerosene and asphalt

Kerosene and asphalt share a small percentage of the overall oil importation in Lebanon. Kerosene is used in the aviation sector and asphalt is used in paving roads, highways, and parking lots.

2.3. Natural gas

Natural gas is an energy source that is preferred over oil derivatives, because it is significantly cheaper and less environmentally polluting. The Lebanese government has recognized the importance of this resource and built two thermal power plants that use NG (Zahrani and Deir-Ammar), such that Syria is supposed to supply Dier-Ammar plant with NG from Baniyas plant. However, after signing the contract and building the pipeline on March 2005, Syria declared that it did not have enough gas

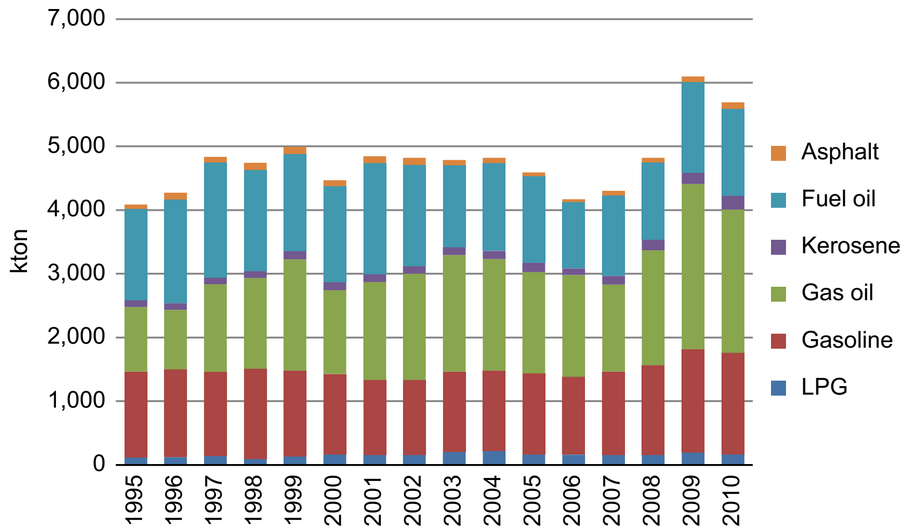

Fig. 5. Evolution of petroleum products importation between 1995 and 2010 (data source: [10] and [4]).

to supply Lebanon [11]. Another NG source is "The Arab Pipeline" which is supposed to supply Lebanon with the Egyptian natural gas [9,5,11]. Moreover, Lebanon could import liquefied natural gas (LNG) as it is located near the major LNG producers in the world (Qatar, Iran, Nigeria and Egypt) [11]. It is worth to mention that transporting LNG is more secure than that of NG as well as it is cost effective [11], but it needs re-gasification centers on the coast. Furthermore, as in the case of oil, natural gas is supposed to be found in Lebanon, according to the geological overview and the previous positive seismic tests. Roudi Baroudi, a leading energy expert, stated that Lebanon contains a huge gas reserve and that "the 11th basin off the Lebanese coast is reported to contain 122 trillion cubic feet of natural gas reserve which is almost three times bigger than Libya's gas reserve" [6]. Therefore, it is the government's responsibility now to accelerate the rate of NG prospecting.

2.4. Recommendations

- Prospect for oil and natural gas on land and offshore.
- Refurbishment of the two existing old refineries in Zahrani and Beddawi.
- Encourage public transport.
- Encourage the use of hybrid, biodiesel and biogas vehicles.
- Develop a rail network among the different Lebanese cities as well as between Lebanon and Syria.

3. Renewable energy in Lebanon

Renewable energy is the energy produced by a natural energy resource such as hydro, solar, wind, biomass, geothermal, tides and waves, etc. These natural resources are free and continuously replenished. However, renewable energy generation systems are still more expensive than conventional ones and choosing to invest in these systems is a matter of resource availability and cost optimization.

Renewable energy currently plays a marginal role in the energy balance of Lebanon. It shares less than 5% of the TPES and less than 10% of the electricity production. Hydro power is the unique renewable source used in electricity generation, although Lebanon has the potential to benefit from other resources, especially solar and wind. Here comes a brief highlighting over the renewable energy potential in Lebanon.

3.1. Tides and waves

Lebanon has 220 km of shoreline on the eastern side of the Mediterranean Sea, which is considered relatively long compared to its area (10452 km^2). However, Houri [1] stated that the Mediterranean Sea is almost a closed sea with minimal variation in tides and relatively small waves for most of the year, which makes it inefficient to invest in such a resource. Another barrier to exploit in this RE source is the narrow shallow part of the coast and the steep slope of the seabed that soon reaches 1.2 m depth, knowing that most of the current technologies for waves and tidal energy need wide, shallow water or a deep but flat seabed as stated by Beheshti [11].

3.2. Wind energy

The potential of wind energy principally depends on wind speeds whose data, for Lebanon, has long been dependent on measurements taken by meteorological stations and some research studies [5,12,13]. Houri [1] and Beheshti [11] reported that significant wind speeds exist in various areas of the country, especially in the North and South. However, all researchers met at the point that the available wind information is not sufficient to develop a wind energy project and that a national wind map or atlas is a prerequisite for trustworthy wind energy study. Effectively, the Ministry of Energy and Water with the support of the United Nations Development Program (UNDP) through the CEDRO project succeeded in launching the first version of the "National Wind Atlas for Lebanon" on January 25, 2011. It is believed that this atlas will create a growing momentum in Lebanon towards strengthening and developing the wind energy sector in the country. The atlas estimated a wind potential of at least 1500 MW [14]; however, most high wind speeds exist in remote areas, specifically on top of mountains, where the total wind power investment may be very expensive. Mourtada [3] indicated an effective potential installed onshore wind power capacity of 250 MW based on the data given by the wind atlas. This wind potential seems to be more realistic and efficient. Moreover, the electricity generation in Lebanon is restricted, by law, to one public company (EDL) and thus, exploiting wind energy for power generation is a governmental decision. Average wind speeds for each month in different Lebanese zones are presented in Table 1. This table shows low mean wind speeds in the majority of zones; however, Fig. 6(a) and (b), which show the

onshore and offshore wind power density maps of Lebanon at 80 m above ground level, reveal the availability of high wind potentials in several regions of the country, especially in the north (onshore and offshore), south and top of mountains.

3.3. Hydropower

Lebanon is popular for its temperate climate and its cold high mountains in an almost desert region. Therefore, it obviously benefits from an important annual amount of water recourses (8600 MCM), coming from rain and snow. However, approximately, only 20% of the received water is being usefully exploited [15]. Hydropower was introduced in Lebanon long ago, where several plants have been installed. In 2009, it shared about 4.5% of the total generated electrical energy [4]. This generation rate can, and should, be increased in the near future by constructing new dams on major rivers. MEW has previously developed a 10-year program (2005–2015) in the aim of making use of available national water resources [5]; however, only 205 MW-capacity hydropower plants were planned for, because priority was

Table 1
Wind speed data for Lebanon in m/s (data source: [14]).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Long term mean wind speed
Beirut Airport	3.4	3.7	3.5	3.1	3.2	3.2	3.4	3	2.8	3	2.7	3.6	3.2
Beirut Golf	3	3.3	3	3.1	3	3	3.1	2.7	2.5	2.3	2.2	2.5	2.8
Tripoli	1.9	2.4	2.3	2.4	2.2	2.1	2.3	2	1.9	1.6	1.6	1.8	2
Sour	3.3	3.4	3.2	3.1	2.9	3	3.1	2.8	2.9	2.6	2.8	2.9	3
Klaiaat Akkar	7.2	6.1	5.1	4.5	3.5	3.3	4.2	2.5	2.8	1.8	3.9	5.4	4.2
Abde	2.4	2.9	3	2.9	2.5	2.6	2.7	2.4	2.3	2.3	2.5	2.4	2.6
Les Cedres	4.4	4.6	4.2	4.5	4.1	3.5	3.3	3.1	3.3	3.9	3.7	4	3.9
Dahr-el-Baidar	6	6.1	6.1	5.9	5.5	5.3	5.8	5.5	5	4.3	4.3	4.9	5.4
Bayssour	4.2	4	4	3.6	3.3	3.2	3	2.6	3	3.2	3.4	3.6	3.4
Zahle	2.6	2.7	2.7	2.9	2.7	2.9	2.9	2.6	2.4	2	1.9	2.5	2.6
Rayak	3.3	3.7	3.8	4.1	3.7	3.8	3.7	3.5	3.4	3	3.1	3.6	3.6
Qaraoun	4	4.2	4.2	4	3.8	3.6	3.6	3.4	3.5	3.7	3.7	4	3.8
Faqra	2.7	3.2	2.9	2.5	2.4	1.8	1.7	1.6	1.8	2.4	2.6	3.1	2.4
Hermel	3.2	3.2	3.5	3.4	3.3	3.1	3.8	2.8	2.8	2.5	2.1	2.9	3.1
Marjayoun	5.9	8.1	7.3	−1	−1	8.9	9.1	−1	−1	7.4	6.8	6.4	−2
Zahrani	4	4.6	4.3	4.1	4.2	3.7	3.7	3.6	3.7	3.9	4	4.1	4

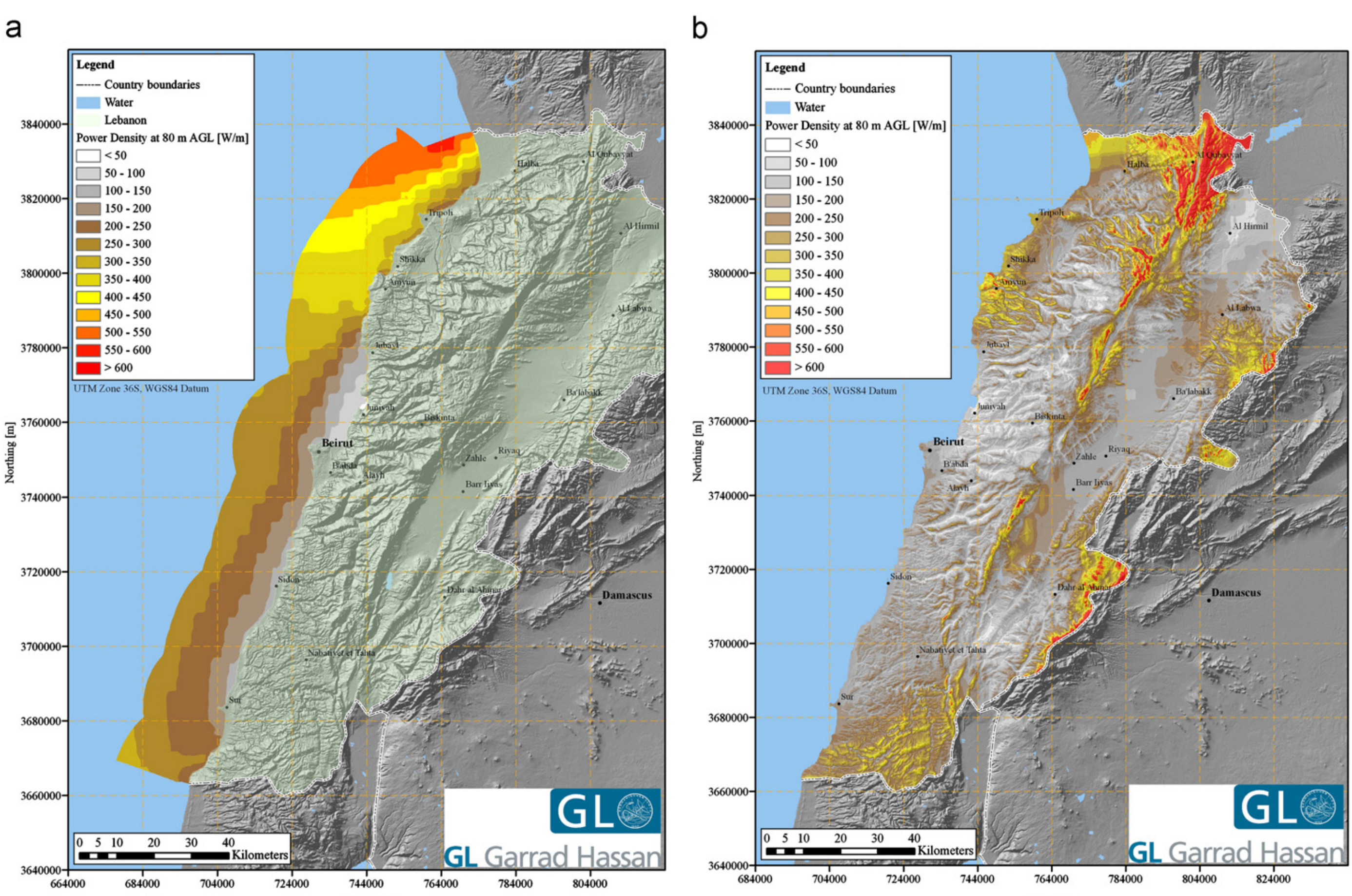

Fig. 6. (a) Wind power density map of Lebanon at 80 m above ground level [14], (b) Offshore wind power density map of the region lying up to 20 km from the coast of Lebanon at 80 m above ground level [14].

Table 2
Future hydropower plants [16].

River	Plant	Capacity (MW)	Conditioned to dam erection
Litani	Bisri	6	No
	Khardali	20	Yes
Safa	Zibli	4.5	No
	Richmaya	4.5	No
	Damour	4.5	No
Ibrahim	Hneidi	20	No
	Jannah	40	Yes
Assi	Yammouneh	10	Yes
	Hermel	50	Yes
Bared	Boumoussa	12	No
	Hamra	16	No
	Kasim	5	No
	Kottine	17.5	No
Abou Ali	Bchenine	4	No
Total		205	

assigned to irrigation. Table 2 illustrates the planned, future hydropower plants.

3.4. Biomass

Biomass is defined as material of recent biological origin, derived from plant or animal matter. It can be combusted to produce heat and consequently electrical energy through steam turbines, or it can be converted into other energy products such as biogas or biodiesel. Wood in the forests is an important biomass source. Forests used to cover 35% of the Lebanese area in 1965 but nowadays, it constitutes no more than 13% [17]. Thus, using wood to produce energy is not recommended in Lebanon as the available quantity is too small and is highly law protected [5]. Another biomass source is the municipal solid wastes (MSW) which are available at a rate of 4300 tons/day [18]. This quantity of MSW could provide about 107 MW of the electricity needs based on an electrical generation rate of 600 kW h/ton [19]. However, due to lack of emissions' control and strong resistance from locals, this energy resource is being avoided. Additionally, Houri [1] reported that MSW, in Lebanon, is more valuable if the raw material is recovered and recycled due to lack in natural resources. Furthermore, biogas – a methane gas produced by the fermentation of organic waste materials – and biodiesel – a plant oil or animal fat, based diesel fuel – are supposed to cover 4% of the Lebanese electrical needs [9].

3.5. Geothermal energy

Previous investigations revealed the existence of underground hot water and thermal vents in different regions like Sammaqiye, Qubayat in Akkar and the offshore of Tyre. However, the detected hot water temperatures are not sufficient for electricity generation from steam turbines, but they can cover some of water heating or space heating loads [9]. It is worth to mention that some regions of Lebanon (extreme north and extreme southeast) used to be volcanic [20]. This fact reflects a high probability for the existence of important geothermal energy in the country. Thus, future researches and investigations are supposed to clarify the truth and remove all doubts.

3.6. Solar energy

Lebanon is rich in solar irradiation during almost 300 days per year, resulting in an average daily solar insolation of 4.8kw h\m^2 [3]. Fig. 7 illustrates measured average daily insolation for each month. The graph clearly shows wide variations between summer and winter months.

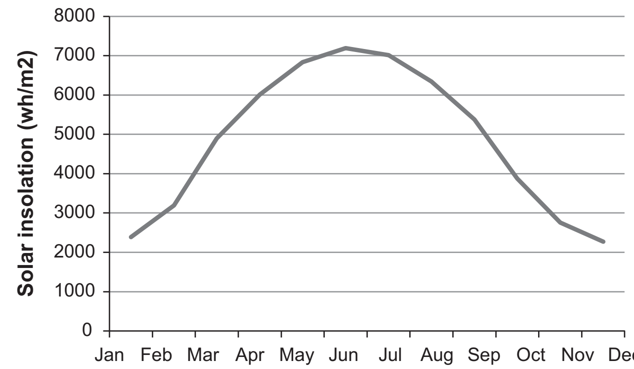

Fig. 7. Average daily solar insolation in Beirut throughout the year (data source: [21]).

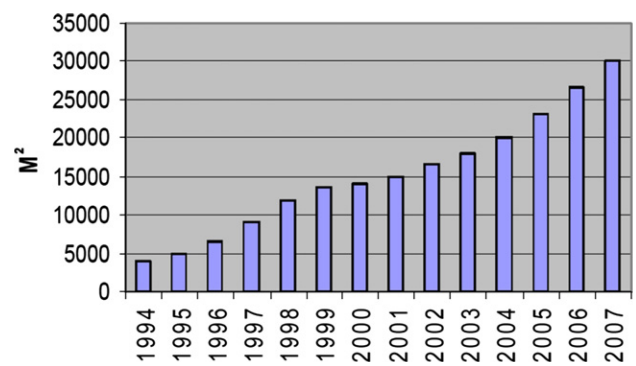

Fig. 8. Evolution of annual installed solar thermal system areas in Lebanon [10].

The illustrated data for solar insolation in Beirut was found to be in high agreement with the data given by [22].

In the field of renewable energy, solar radiation is usually captured and converted into heat (solar thermal) through solar absorbing panels or into electricity through photovoltaic modules.

3.6.1. Solar photovoltaic (PV)

Solar photovoltaic (PV) is used to generate electrical energy by converting solar radiation into electrical current. Solar irradiation is readily available in Lebanon; however, adopting this technology faces several barriers. For instance, high initial cost, low efficiency per unit area, lack of PV market and immaturity of technology. Thus, the photovoltaic solution is recommended to wait for further technical and economic development. However, at the present time, it could be a good solution for isolated areas that suffer from frequent or emergent electrical outages [5].

3.6.2. Solar thermal

Solar water heating systems (SWHSs) represent about 3% of total installed residential water heaters in Lebanon [23]. This percent share is considered very small relative to the annual available solar radiation that is capable of producing more than one million toe using solar thermal technology, as reported by Abi Said [5]. Fig. 8 illustrates the evolution of annual installed area of solar thermal systems between 1994 and 2007. It clearly reveals an increasing installation trend, which reflects more awareness, acceptance and observed savings among the Lebanese.

It is well known that most Lebanese households are equipped with electrical water heaters. Table 3 presents the percentage distribution of various domestic water heating systems in Lebanon obtained from different studies. It is clear that most residents rely on electric heaters for hot water production and this adds an

Table 3
Water heater distribution by type.

Data Source	**Electric** (%)	**Gas** (%)	**Oil** (%)	**Wood** (%)	**Solar** (%)
[24]	60	8 (+Wood)	31	8 (+Gas)	1
[25]	82	15.2 (+Oil and wood)	15.2 (+Gas and wood)	15.2 (+Gas and oil)	2.8
[5]	70	10	10	5	1
Study by Saint Joseph University [9]	70	5 (+wood and solar)	25	5 (+gas and solar)	5 (+gas and wood)
[23]	75	22 (+oil and wood)	22 (+gas and wood)	22 (+gas and wood)	3

unsustainable burden on the Lebanese electricity sector. Therefore, an important portion of the residential electrical consumption may be saved by the adoption of SWHSs especially if their use is extended to cover space heating. LCEC – Lebanese Center for Energy Conservation – reported that 1000 GW h of conventional electricity generation could be saved by increasing solar collector area [26]. Economically, it is indicated that the average payback period of the installed solar hot water system is around 4–5 years [9], if it is supposed to replace an electric water heater. Another study conducted by LCEC, reported a maximum payback period of 3 years [27]. Recently, solar water heater loans came to the financial markets in Lebanon and several banks have started to offer funding opportunities for such systems as to motivate the solar thermal market. Despite this analysis, urban Lebanese areas consist of multi-floor apartments and thus, the free space is very restricted. This could be a limiting factor concerning solar water heating system installations in the country.

Concerning the electricity generation using the solar thermal, concentrating solar power (CSP) systems are usually utilized. These systems use mirrors to concentrate the direct solar radiation (beam) and produce steam which, in turn, is used to produce electrical energy through steam turbines. CSP systems need large free flat portions of land; however, this requirement is limited in a small size and mountainous country like Lebanon.

3.7. Barriers

- No regulations for EE or RE existing until now.
- Energy auditing is not obligatory yet.
- Absence of official EE or RE agencies.
- High initial cost of EE and RE devices.
- Lack of financial incentives (loans, tax breaks, subsidies, TVA exceptions, import tax reductions etc.).
- Low competition due to the current low electricity tariffs (electricity tariffs do not reflect the real cost).
- Lack of adequate advertisement about EE and RE.
- Lack of public awareness to the benefits of using EE and RE devices.
- Lack of reliable data for solar and water resources [28].
- Lack of the necessary studies for some RE technologies such as wind, geothermal, solar PV etc.
- Absence of good energy studies that reflect the real long-term cost of EE and RE applications.
- Domestic expertise are not sufficiently considered [3]
- No current national plans exist to reduce greenhouse gas (GHG) emissions, where such plans motivate the EE and RE market.
- Monopoly of EDL that obstructs the participation of the private sector in the electricity generation.
- The absence of a political will in favor of motivating RE technology.

3.8. Recommendations

- Develop EE and RE regulations which enforce energy audits, taxes on conventional electrical equipment, energy intensity labeling etc. [9]
- Exonerate RE-imported systems and components from custom duties [28].
- Develop and implement RE certification directive, which includes standards and procedures for RE technology production and use [9], such as US LEED.
- Oblige the use of EE and RE applications in new constructions.
- Achieve the grid connection for RE systems [28].
- Create an EE and RE department in the Ministry of Energy and Water.
- Develop the EE and RE market.
- Encourage the private sector to invest in the RE sector (SWHS, PV, wind etc.).
- Enhance customers to move towards EE and RE appliances by finding the necessary loans with low interests and revealing the real operating costs and payback periods according to specialized studies.
- Encourage and support EE and RE education and research studies [3, 9].

4. EDL

4.1. Introduction

Electricity of Lebanon (EDL—Electricité du Liban) is a public institution with an industrial and commercial vocation under the control of the Ministry of Energy and Water (MEW). It was founded by Decree No. 16878 dated July 10, 1964, and mandated the responsibility of the generation, transmission, and distribution of electrical energy in Lebanon. Thus, the electricity sector is monopolized by EDL that, currently, controls over 90% of the formal Lebanese electricity sector (including the Kadisha concession in North Lebanon) [29]. Other participants in the sector include hydroelectric power plants owned by the Litani River Authority (public company), concessions for hydroelectric power plants owned by Ibrahim and Al Bared (private companies) that sell their electrical production to EDL, and distribution concessions in Zahle, Jbeil, Aley, and Bhamdoun, which are provided with electrical energy by EDL at cheap prices (50 to 75 LL/kW h as compared to the real cost of 255 LL/kW h [30]).

Before 1975, 11 major power plants, linked in a common distribution network, supplied most of the country's electricity. In 1974, EDL generated 1700 GW h constituting about 85% of all generated electricity [31]. However, during the civil war (1975–1990), the electricity sector infrastructure was subjected to a great damage and ignore. After that, an emergency “Power Sector Master Plan” was launched between 1992 and 2002. It involved the rehabilitation of the existing power plants along with the transmission and distribution networks, increasing of the generating capacity and extension of the transmission network. However, this plan proved to be insufficient and deficient as the demand still exceeds the supply, and daily rationing is common all around the country. It is worth to mention that the rationing differs from one region to another, where the Capital Beirut (excluding suburbs) is subjected to the least rationing period (only 3 h); while some other regions suffer from a daily of 12–13 h blackouts [23]. Back-up self-generation

is estimated to represent up to 30% of all electricity generated [32] and plays an informal complementary role that is participating in assuring nearly 100% electrification together with EDL. Thus, the Lebanese are paying a double electrical bill, one for EDL and the other for the back-up self-generation which is almost twice the EDL bill [23]. Considering this fact, the Lebanese are compelled to pay a high monthly electricity bill as compared with other countries in the region [34], while suffering from a low quality service.

Losses on the grid are reported amounting to 40%, 15% of which corresponding to technical losses and the remaining are non-technical losses [30]. It is worth to mention that non-technical losses have been significantly reduced during the last decade when they were estimated to be approximately 48% [33]. Non-technical losses are attributed either to illegal aggressions or unbilled consumption due to the shortcomings in the billing system. Fig. 9 shows the Lebanese electricity sector profile in 2009.

Electricity, in Lebanon, is principally generated through thermal power plants, in addition to small amount that comes from renewable energy resources through the several, long-ago established hydropower plants. However, no other indigenous resources (solar, wind, biomass etc.) have been exploited in this sector until now and the share of hydroelectric power has severely reduced. In 1974, 41.5% of the total generated electricity was hydroelectric [31] compared to 4.5% in 2009 [30]. A research conducted by CAS (Central Administration for Statistics) reported that 5–12% of electricity production in Lebanon comes from hydropower energy depending on rainfall and thermal plants productivity [9].

The distribution of electricity among different sectors is: 45% for residential and business sectors (i.e., low-voltage demand), 23% for industry, 12% for administrative buildings, 5% for concessions, and 15% for technical losses [5]. Houri and Korfali [35] reported that the residential sector consumes 65–73% of the electricity produced and when combined with the commercial sector, together consume 80% as stated by Houri [36]. Furthermore, a document of the World Bank stated that electricity is divided equally between the residential and business sectors from one side and the industrial, administrative buildings, and concessions from the other side [34].

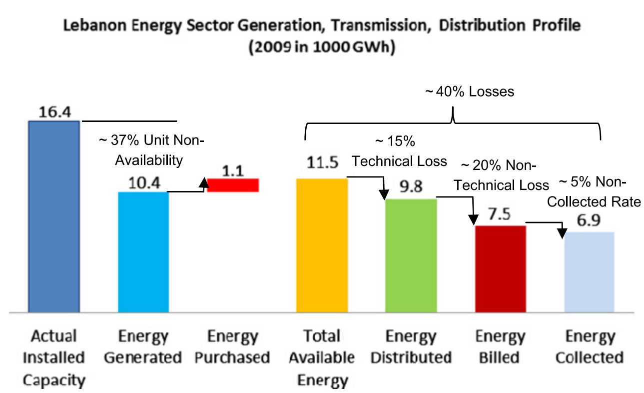

Fig. 9. Lebanon electricity sector: generation, transmission, distribution (data source: [30]).

Administratively, the current number of employees at EDL is around 1700 [37], where it should normally be 5020 employees according to EDL that is serving more than 1100,000 subscribers of low, medium, and high voltage [29].

Financially, the current electricity tariff has been derived from an average oil price of 25 US$/barrel in 1996 and has not changed until now [34]. Actually, this tariff is not capable of covering EDL expenditures even if the institution was assumed to be operating effectively and consequently, EDL is falling deeply into debt and is depending more and more on the governmental subsidies (Fig. 10) which keep it under the mercy and the will of the politicians in order to provide more credits. Thus, a direct adjustment of the tariff to better reflect the cost of electricity is needed.

4.2. Historical overview of the development of electricity regulations in Lebanon

Table 4 presents an overview for historical development of regulations concerning the Lebanese electricity sector.

4.3. Generation

4.3.1. Infrastructure

Currently, power generation plants in Lebanon (Fig. 11) are divided into two categories: thermal and hydraulic. EDL operates six thermal power plants:

- Two combined cycle gas turbine plants (CCGT), Deir-Ammar and Zahrani. Designed to operate using natural gas, these two plants are using gas oil/diesel instead [41].
- Two steam turbine plants, Zouk and Jieh, which operate using heavy fuel oil (HFO) [41].
- Two open cycle gas turbine plants, Baalbek and Tyre, which designed to operate using natural gas, they are using gas oil/ diesel instead [41].

In addition, there is a steam turbine power plant, Alhreesha, which is owned by Kadisha (Property Company of EDL) and uses HFO.

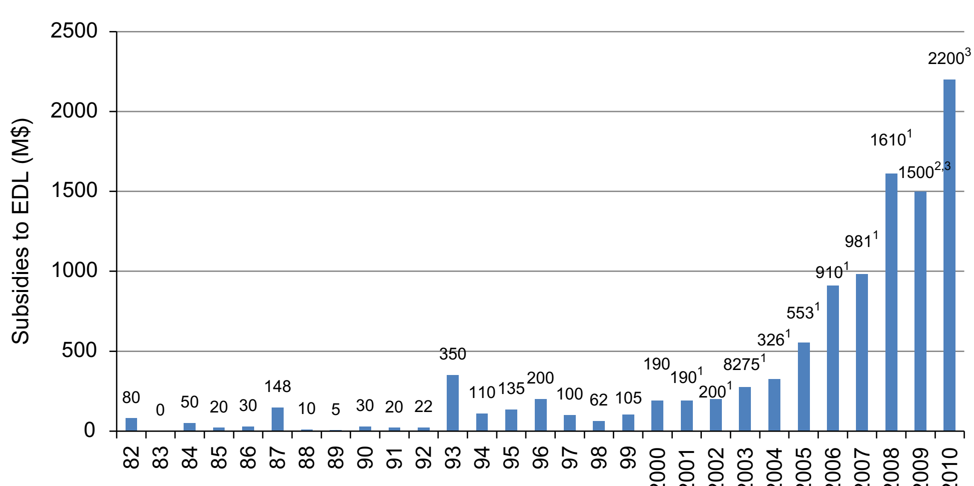

Fig. 10. Subsidies to EDL between 1982 and 2010 (data source: [34], [1][38], [2][30] and [3][4]).

The total installed capacity of these thermal power plants is 2038 MW distributed as shown in Table 5.

As the key performance indicators (KPIs) reflect the real electricity sector, the data of the generation KPIs, i.e., availability factor (ratio of available output energy to maximum possible (rated) output), load factor (ratio of actual energy output to rated output), thermal efficiency and total cost/KW h sent out, is summarized in Table 6 for the six EDL thermal power plants between 2006 and 2008.

The hydraulic power plants are divided into Litani River Authority (public company), Al-Bared and Ibrahim (private companies), and Kadisha (property company of EDL) power plants. These hydro-power plants have a total installed capacity of 273.6 MW distributed as shown in Table 7.

Fig. 12 shows the evolution of electricity production according to the energy source between 1974 and 2010. It is noticed that hydraulic power plants have a small contribution to the total electrical production. Moreover, it could be noticed that both thermal and hydraulic power plants do not have fixed electrical production and change from one year to another.

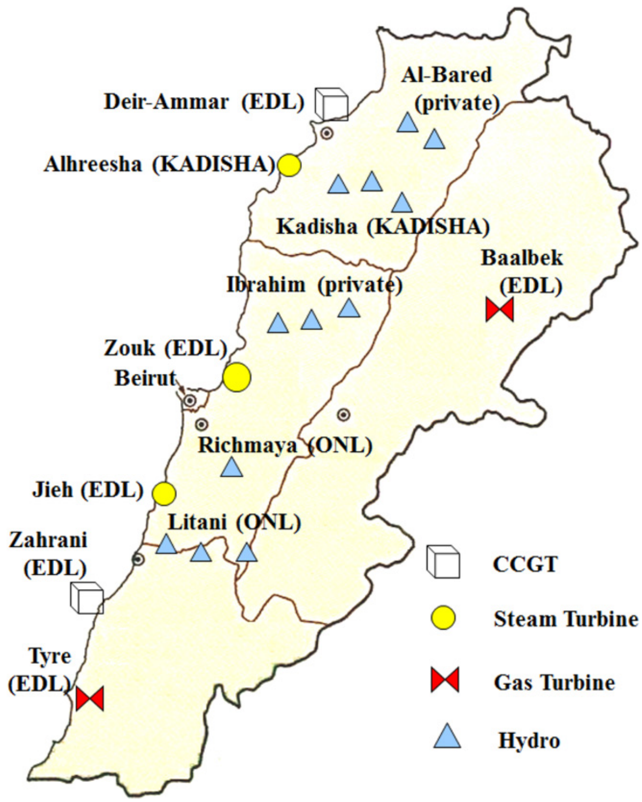

Fig. 11. Power plants in Lebanon (data source: [29] and [41]).

4.3.2. Problems

- There is a serious deficit in the generation capacity which is not being able to meet demand. Fig. 13 reveals the current and forecasting shortage of the power production. It is noticed that the demand increases versus a decreasing rate of supply and this fact increases the shortage gap and exerts large pressures on the government and society.
- There is a limitation and clear aging of two out of four major thermal groups (Zouk and Jieh). This limitation has led to an increase in the technical problems, daily cost of maintenance and severe decrease in thermal efficiencies.
- Despite the fact that four of the generation plants were designed to use natural gas, they are being fuelled by expensive gas oil (diesel) which causes high generation costs. This is because natural gas has not been not yet effectively available.
- In most cases, low quality fuel is used.
- Absence of periodic preventive maintenance [41].
- Load factors are low, thus leading to a decrease in the overall generation capacity [41].
- The generation cost is overestimated because thermal efficiencies of power plants are generally below the normal values [41].

Table 4
Historical regulations overview for electricity sector in Lebanon (data source: [39]).

1907	A concession was granted to a private company, "Nahr Ibrahim", for the purpose of irrigation and hydropower generation from the river "Ibrahim".
1923	The private company "Tramways et Eclairage de Beyrouth" was established in order to construct tramways in Beirut and lighten the city
Between 1924 and 1936	"Kadisha" electricity private company was granted five different concessions to generate, transport, and distribute electricity in cities and villages of North Lebanon
1946	"Bared" concession was granted to generate electric power from the Bared River for 75 years
1954	• Ratification the Beirut Electricity Company Protocol leading to nationalization • Launching a law creating the electricity and public transport authority • Launching a law creating the National Office of Litani river (ONL) which is a public authority responsible for taking care of the irrigation schemes and hydropower generation
1964	Establishment of "Electricity of Lebanon" (EDL), a public company, which was mandated the responsibility of the generation, transmission and distribution of electrical energy in Lebanon
1972	Issuance of the general order for the public authorities which governed both Litani River Authority and EDL
1985	Recuperation of the Kadisha Electricity Company
1995	• Enabling EDL to invest $1.29 billion in several electrical activities • Taking over the hydropower company of Nahr Ibrahim
1996	The Lebanese Government was allowed, by law no. 621, to contract for loans with international funding agencies for the 220 kV electric transmission system expansion
1997	Launching the Penal Law no. 632 that stated that electricity and illegal connections are crimes penalized by imprisonment
1998	First proposal of the new electricity law
2000	• Launching the privatization law no. 228 that covered privatization procedures and conditions • Approve of the draft law for the organization of the electric sector by the Government and transferring it to the Lebanese Parliament
2001	A draft concerning the new electricity law was sent to the Parliament
2002	Launching of the new electricity law no. 462 [40]
2011	Forming a ministerial committee to study the necessary modifications for the law 462

Table 5
Installed capacity of thermal power plants (data source: 1. [29], 2. [5], 3. [34]).

Thermal plant name	Installed capacity (MW)	Available capacity in 2008 (MW)	Commissioning date	Date of retirement	Type of fuel
Zouk (ST)	607[1]	365[3]	1984–1987[2]	2015[2]	HFO
Jieh (ST)	346[1]	187[3]	1971–1981[2]	2010[2]	HFO
Alhreesha (ST)	75[1]	60[2*]	1983[2]	2010[2]	HFO
Tyre (GT)	70[1]	70[3]	1996[2]	2021[2]	DO or NG
Baalbek (GT)	70[1]	70[3]	1996[2]	2021[2]	DO or NG
Zahrani (CC)	435[1]	435[3]	1997–1999[2]	2025–2030[2]	DO or NG
Deir-Ammar (CC)	435[1]	435[3]	1997–1999[2]	2025–2030[2]	DO or NG
Total	2038				

* Available capacity in 2003.

Table 6
Generation KPIs of power plants (data source: [42,43], and *[41]].

KPI	Availability factor (%)			Load factor (%)			Thermal efficiency (%)			Total cost/kW h sent out (US$)		
Year	2006	2007	2008	2006	2007	2008	2006	2007	2008	2006	2007	2008
Zouk	52.0	54.0	53.0	44.0	40.4	53.0	34.2	36.0	33.2	9.1*	0.11	0.19
Jieh	62.0	74.4	74.0	53.0	54.0	63.0	29.7	28.9	30.3	10.42*	0.13	0.20
Deir-Ammar	64.4	96.0	97.0	59.5	53.0	82.3	44.4	46.0	47.7	11.64*	0.13	0.21
Zahrani	77.9	92.0	91.0	50.8	73.0	76.3	44.9	46.0	46.1	11.4*	0.13	0.21
Tyre	44*	80.0	NA	20.8	24.1	43.4	26.8	28.7	28.1	19.2*	0.22	0.32
Baalbeck	44*	97.6	NA	22.9	64.5	42.7	28.4	28.0	28.1	18.2*	0.20	0.32
System Average	62.0	78.0	77.0	47.8	49.8	60.0	39.6	38.8	40.0	NA	0.13	0.20

NA: Not available.

Table 7
Installed hydropower plants (data source: [29,9]).

River	Hydropower plant name	Installed capacity (MW)	Installation date	Owner
Litani	Awali	108	1965	Litani River Authority (Public company)
	Joun	48	1968	
	Abed Al	34	1961	
Al-Bared	Al-Bared1	13.5	1954	Private
	Al-Bared2	3.7	1962	
Safa	Safa/Richmaya	13.4	1932	Litani River Authority (Public company)
Kadisha	Balouza	8.4	1961	Kadisha (Property company of the EDL)
	Abu Ali	7.4	1933	
	Mar Lichaa	3.1	1952	
	Bacharre	1.6	1929	
Ibrahim	Ibrahim 1	15	1962	Private
	Ibrahim 2	12.5	1956	
	Ibrahim 3	5	1950	
Total		273.6		

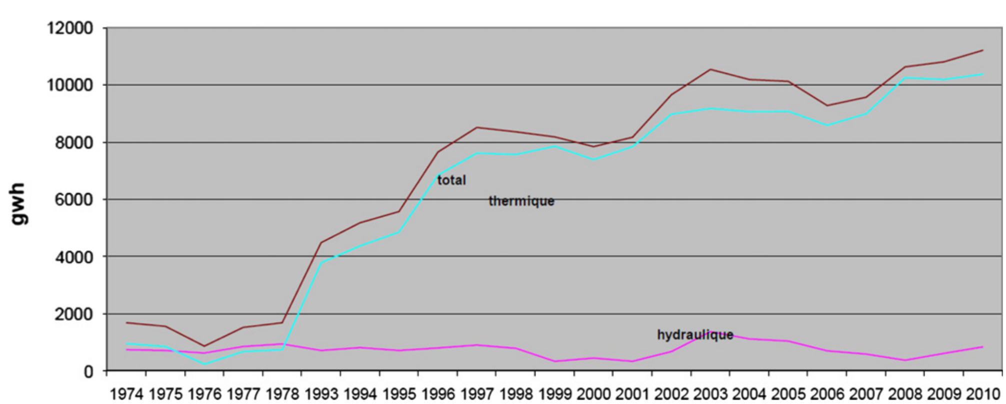

Fig. 12. Evolution of electricity production by source [4].

- Lack of computerized maintenance management system (CMMS) [44].
- Lack of proper and clear administrative orders to request fuel shipment on time. Moreover, oil installations (Zahrani and Tripoli) were forced to provide EDL with the stock market prices and the transfer of fuel in tanks, leading to additional losses.

4.3.3. Recommendations

- The immediate substitution of diesel oil by Natural Gas for operating Deir-Ammar and Zahrani thermal power plants [30,34,45].
- Rehabilitation of the existing power plants in Jieh and Zouk [30,46].
- Develop new hydro [30] and thermal power plants [30,45,46]
- Periodic preventive maintenance is required.

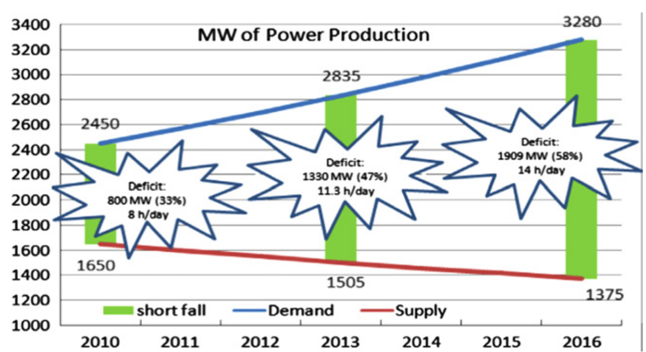

Fig. 13. Forecasting of the power shortage (data source: [37]).

- Implement computerized maintenance management systems (CMMS).
- Establish regional electricity interconnections with the neighboring countries (Syria, Jordan, Egypt, Turkey) [30,45].
- Diversify the power supply system in order to cope with insecurities in power supply (by sources of energy, suppliers, plant types, operators, etc.) [30,46,47].
- Allow the private investment in the RE-electricity generation by implementing of a decentralized strategy for energy generation [9,47].
- Legalize the private generator businesses for a transition phase as a part of an electricity strategic plan [32,47].

4.4. Transmission

4.4.1. Infrastructure

EDL transmission network consists of four types of high voltage power lines: 66, 150, 220 and 400 kV, noting that the latter lines serve to connect the 400 kV station in Ksara with the Syrian 400 kV network. This regional electrical interconnection is not operational until now due to the lack in the infrastructure of Ksara substation [30]. The HV lines have a total length of about 1427 km [30]. Furthermore, EDL owns 58 major power substations converting power from high voltage to medium voltage [29]. The Transmission Directorate, within EDL, is mandated the responsibility of constructing, managing, controlling, dispatching, monitoring and maintaining all transmission networks in Lebanon. Fig. 14 shows an organigram of the Directorate.

Tables 8 and 9 summarize the transmission substation assets and transmission lines and cables across EDL in 2006. Table 10 shows the transmission loss rates for years 2006, 2007 and 2008.

Fig. 15(a), (b) and (c) show the 220, 150 and 66 kV transmission lines maps of Lebanon, respectively.

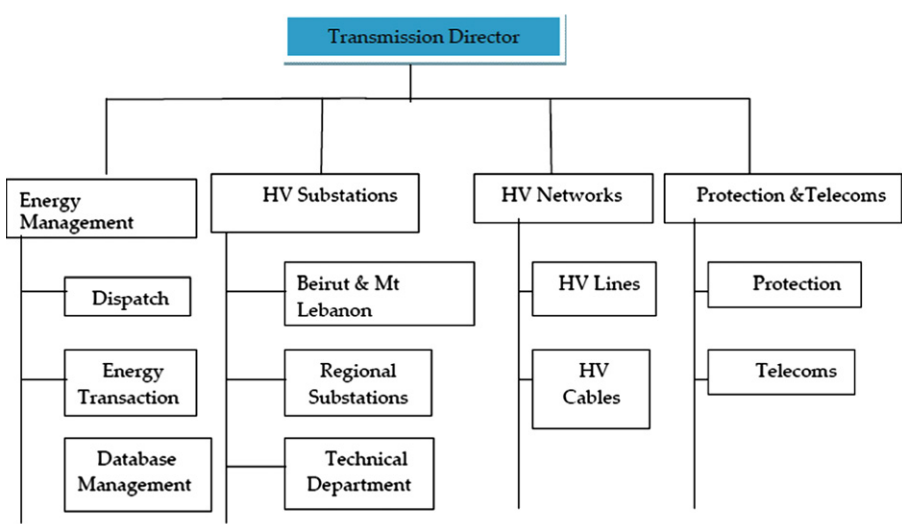

Fig. 14. Organigram of Transmission Directorate [41].

Table 8
EDL-Transmission substations, lines and cables in 2006 (data source: [41]).

Voltage	220 kV				150 kV		66 kV			
Type of substation	2201506624	22015024	2206624	22024	1506624	1506611	6624	6620	6615	6611
No. of substations	2	1	7	2	3	1	31	4	5	3
Total	12				4		43			
Transmission lines (km)	466				164.19		530.77			
Transmission cables (km)	59.98				27.94		92.03			
Total	526				192		623			

Table 9
Private utilities network transmission lines in 2006 (data source: [41]).

Description	Voltage	Total Length (km)
Kadisha	66 kV	96.7
Litani Office	66 kV	69.5
Ibrahim	66 kV	13.6
Bared	66 kV	104.5
Total	66 kV	284.3

Table 10
Transmission loss rate (data source: [48]).

Year	**2006**	**2007**	**2008**
Transmission Loss Rate (%)	4.0	4.0	3.5

4.4.2. Problems and recommendations

Problems	Recommendations
• High technical losses (~15%) [30]. • Approximately 11% of the transformers are out of age [41]. • Lack of computerized management information systems [40,43]. • The 220 kV tension line network has not completed yet. • HV porcelain lines and glass HV insulators have negative environmental effects [41]. • Standby power capacity is negatively affected by operating HV transformers at high load factors [41]. • "Load shedding occurs throughout the year, mainly during the day, and much less during the night" [41]. • Complexity of material purchasing is delaying the work programs [40,41]. • No financial independency within the Directorate to ensure good functionality.	• Prioritize network improvement through the implementation of a network disturbance/fault analysis [41]. • Establish management control and information systems [40,43]. • Complete the 220 kV line which, if accomplished would reduce the technical losses and ensure the network reliability [30], [45]. • Many HV lines require replacement [41]. • Atmospheric pollution motivate the replacement of HV porcelain lines and glass HV insulators with composite types across the networks. • Allocation of a sufficient budget for the Transmission Directorate in order to enhance its financial independency, at least for the procurement of low cost materials.

4.5. Distribution

4.5.1. Infrastructure

The distribution network consists of substations that convert power from medium to low voltage, using more than 18,000 transformers [30]. The distribution networks are primarily supplied at 11, 15 and 20 kV with the nominal low voltage (LV) being 380/220 V [41]. Two Distribution Directorates, "Beirut and Mount Lebanon Directorate" and "Regions Directorate", are mandated the responsibility for managing the distribution networks in Lebanon, each within its geographical remits. Network maintenance and planning, public-lighting maintenance and studies, metering, billing, collection and customer services are the major functions handled by these directorates. Fig. 16 shows an organigram of the two Distribution Directorates.

Tables 11 and 12 summarize the Distribution Substation assets across EDL and Table 13 illustrates the distribution loss rates between 2006 and 2008.

4.5.2. Problems and recommendations

Problems	Recommendations
• Existence of uncollected electrical consumption bills (~5% in 2009 [30]). • High non-technical losses (~20%) [30]. • No planned maintenance of the MV/LV substation assets exist and problems arising are dealt with on a "action-reaction" basis [41]. • 37% of the MV/LV transformers have exceeded their average lifetime [41]. • Substations and equipment are classified as very old and poor [41]. • Lack of safety equipment that the staff need [42]. • The vehicles of the distribution Directorate are very old and poorly maintained, and this is obstructing the job rate [40,41]. • Lack of good contractor workmanship. • Lack of computerized management information systems [40,43]. • Complexity of material purchasing is delaying the work programs [40,41]. • No financial independency within the Directorate, to ensure good functionality.	• Reduce the unpaid consumption of electricity. • Install a modern and efficient billing and metering system [30,45]. • Reduce the electricity theft and illegal connections by application of the penal law No. 632. • Improve and develop the distribution network [30,45]. • Prioritize network improvement through the implementation of a distribution network continuity analysis [41]. • Set organized, planned maintenance programs [41]. • Carry out planning studies. • Improve and develop the assets. • Purchase safety tools for the staff. • Purchase new vehicles. • Initiate of remedial actions such as inspecting and recording defects, fault monitoring, etc [41]. • Implement Geographic Information Systems for Electricity of Lebanon (GISEL) [49] that would provide EDL with the tools for collection, monitoring and management, and consequently reduce the non-technical losses and aid the Distribution staff in their work. • Allocate a sufficient budget for the Distribution Directorate in order to enhance its financial independency, at least for the procurement of low cost materials.

4.5.3. Services

The Distribution directorates of EDL are responsible for the services job. This job includes metering, billing, collection and customer service. The services job is suffering from several

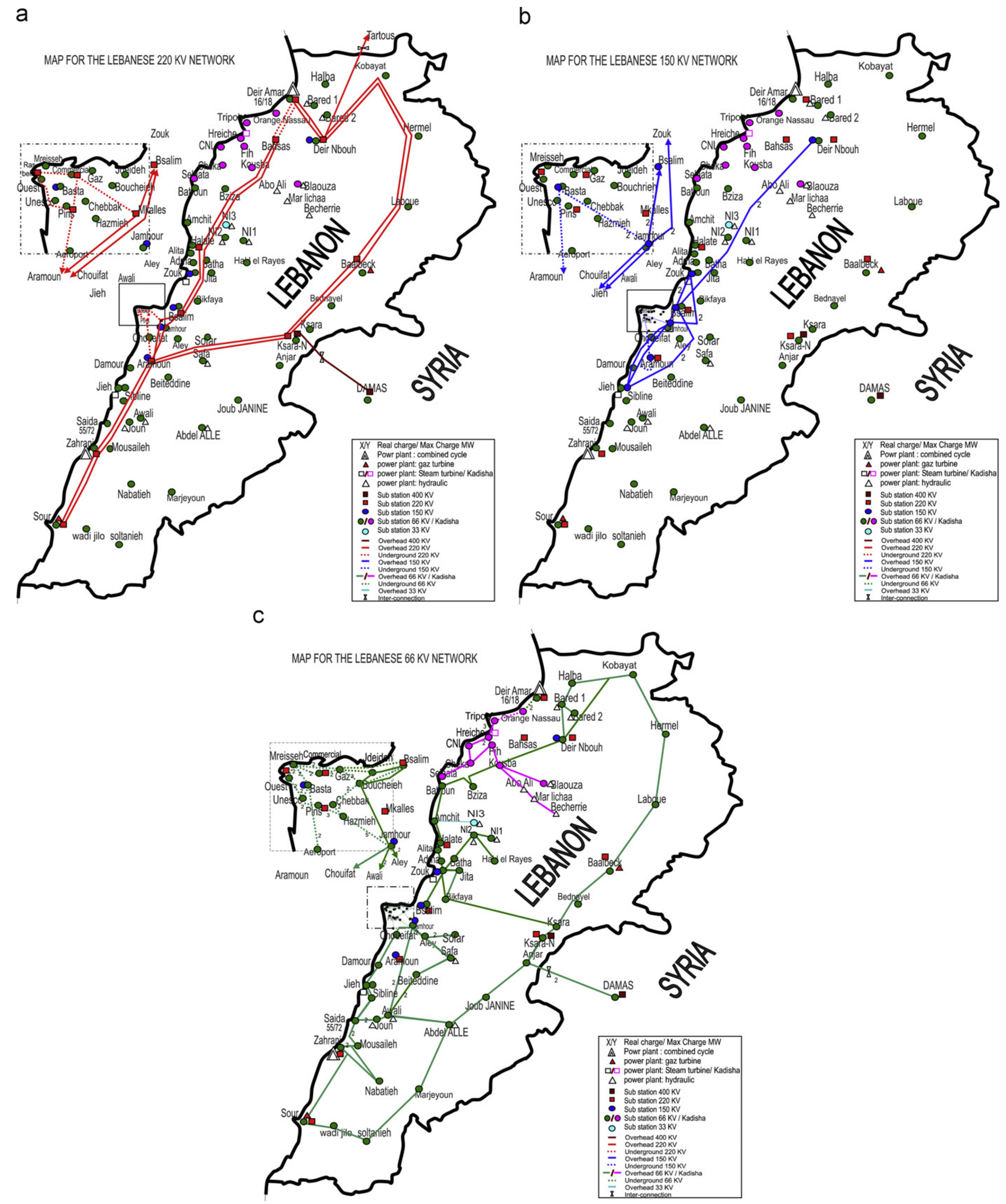

Fig. 15. Map Transmission lines (a) 220 kV; (b) 150 kV; (c) 66 kV [28].

problems such as non-qualified staff, manual billing and collection system, reliance on individual contractors (collectors) for reading the meters and collection of bills and absence of periodic tests and checks on the installed meters at the customer's sites. Thus, it is recommended that the staff be a part of EDL employees and train them well, adopt an updated billing and collection system and test the meters periodically. Table 14 shows the collection rate per region for LV and MV metered customers in 2007.

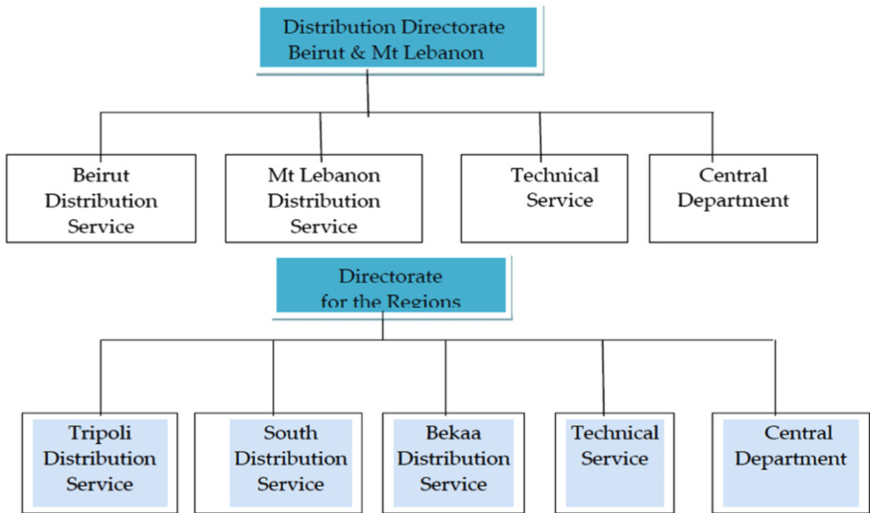

Fig. 16. Organigram of Distribution Directorates [41].

Table 11
EDL-substation age profile at the end of 2006 (data source: [41]).

Service area	No. of substation	0–10 years	10–20 years	20–40 years	Over 40 years
Beirut	4,956	1,207	1,092	2,272	385
Mt Lebanon	4,243	1,306	1,813	1,031	93
North	1,612	575	656	333	48
South	3,945	958	1,699	1,199	89
Bekaa	2,084	544	800	699	41
EDL (total)	16,840	4,590	6,060	5,534	656
%	100	27	36	33	4

Table 12
Number of substations at each voltage level at end of 2006 (data source: [41]).

Service area	No. of substations	5 kV	11 kV	15 kV	20 kV
Beirut	4,956	–	4,029	729	198
Mt Liban	4,243	96	14	3,533	600
North	1,612	32	–	1,460	120
South	3,945	–	–	3,771	174
Bekaa	2084	–	–	2,075	9
EDL (Total)	16,840	128	4,043	11,568	1,101
%	100	0.8	24	68.7	6.5

Table 13
Distribution technical loss rate (data source: [48]).

	2006	2007	2008
Distribution technical loss rate (%)	11	11	9

4.6. Administrative status

- The average age of the employees in EDL is about 52 years [30] with a huge shortage that reaches more than 60% of the supposed existing staff as a result of non-employment governmental policy [42].
- The adopted recurrent administrative configurations is assigning non-qualified people and transferring skilled engineers to small departments. This fact negatively affects the system work efficiency.

Table 14
Collection rate for LV and MV in 2007 (data source: [48]).

	Beirut	Mount Lebanon	Bekaa	North	South
LV Collection Rate (%)	97.54	83.46	87.15	84.03	84.19
MV Collection Rate (%)	99.92	98.62	97.24	93.81	97.80

- Loss of the institution's independence due to the ongoing political interference in the work of administration, administrative appointments, and employments.
- Absence of computerization and need for information technology (IT) equipment.
- Lack of operational studies and absence of clear operational planning.
- Lack of knowledge in the field of financial and technical administrative oversight of the authorities concerned.
- Absence of transparent financial and non-financial reports represented in non-auditing of the accounts since 2001 [45].

4.6.1. Recommendations

- Appointment of well-qualified young employees having high technical and managerial skills to improve EDL tasks and support the introduction of renewable energy sources.
- An overhang of the currently retired staff for more few years could be beneficial in order to pass their expertise to the new generation and help in the restructuring of EDL.
- Encourage collectors to be more productive in work by providing them financial incentives [50].
- Adoption of a document backup software to save files and improve the existing archive system.
- Activate the administrative links between the General Directorate and other Directorates.

Fig. 17 illustrates a forecasting of the EDL staff shortage between 2009 and 2015. It reveals a current huge staff shortage, which is expected to reach more than 72% in 2015.

4.7. Financial status

- Tariffs are much lower than the actual cost of the produced electricity. The average cost of electrical production in 2009 was 255 LL/kW h (0.17 US$/kW h) [30] compared to an

Table 15
Tariffs of electric consumption in Lebanon [29].

Tension	Type of subscription	Consumption (kW h/month)	Tariff (LL/kW h)
Low	1-Lighting, home and commercial use	Up to 100	35
		Between 100 and 300	55
		Between 300 and 400	80
		Between 400 and 500	120
		Above 500	200
	2-Streets Lighting, public establishments, free medical care centers, hospitals, mosques, churches, cinemas, charity groups and hotels	For each kW h/month	140
	3-Industry, craftsmen, agriculture, water treatment and pumping stations	For each kW h/month	115
Medium	1-Industry, craftsmen, agriculture	Active energy (for each kW h/month)	130
		Reverse energy (for each k.v.a.r.h/month)	50
	2-The rest of subscribers	Active energy (for each kWh/month)	140
		Reverse energy (for each k.v.a.r.h/month)	50
High	-	Active energy (for each kW h/month)	115

Note that all the charity organizations, free medical care centers, and hotels have the right to choose for one final time between the tariff in category 1 and that in category 2 of Low tension [29].

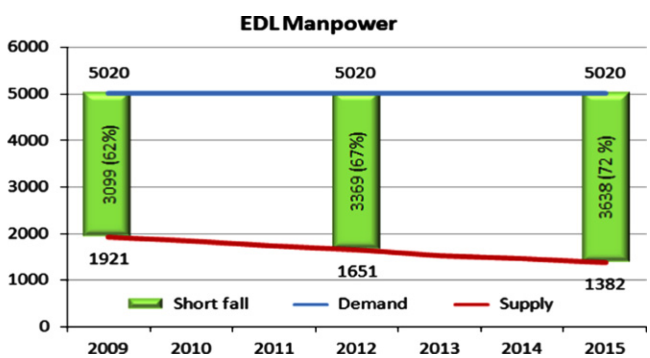

Fig. 17. EDL man power forecasting (data source: [37]).

average bill of 141 LL/kW h (0.094 US$/kW h) [34]. Thus, EDL is losing with each kW h sold and the losses will increase as it sells more.

- The current electricity tariff has been derived from an average oil price of 25 US$/barrel in 1996 and has not changed till now [34].
- Bad investment in new plants added additional losses instead of increasing the revenues (OCGT instead of CCGT in Tyre and Baalbek power plants).
- EDL is falling deeply into debt and depending more and more on the governmental subsidies (~2200 M$ in 2010) which keeps it under the mercy and the will of the politicians to provide more credits.
- The contribution of the fuel bill to EDL total budget was around 1450 M$ (75%) and 1165 M$ (62%) in 2008 and 2009, respectively. This reveals the high price of fuel that is negatively affecting the financial status of EDL.
- Inability of the company to prosecute the aggressors to the network. Note that most of electrical thefts are covered by the political leaders.
- Lack of seriousness in bill collections and the weakness of follow-up mechanisms that resulted in an increase of arrears, which amounted to hundreds of billions LL.
- Lack of an internal auditing system which negatively affects the accuracy of institution's financial accounts [42].
- Absence of a computerized accounting system that links all the institution accounts [42].

4.7.1. *Recommendations*

- Adjust the tariff to better reflect the cost of electricity production, transmission and distribution [47,38].
- The basis of the electricity tariffs has to be improved, as low power consumers induce higher costs for production, transmission and distribution than that of high power consumers.
- Reduce the production cost by changing the preparation of fuel tenders in order to make them more transparent and fit the international standards [50].
- Establish a feed-in law that allows local energy producers, through renewable installations, to sell the generated electricity to public or private sectors.

4.8. *Tariffs*

In Lebanon, the total electricity consumed is divided into several subsections. Tables 15 and 16 illustrate, in details, the tariff for each subsection according to the type of both tension and subscription (e.g., home, public, industry etc.). These tariffs have been implemented since August 1, 1994.

5. Electricity plans for Lebanon

This section presents a summary of the last three official reform plans for electricity sector in Lebanon. They were proposed by the ministers: Mohammad Fneish in 2006, Alain Tabourian in 2008 and Jebran Bassil in 2010.

Table 17 reveals large similarities among the recommendations suggested in plans of ministers Fneish and Bassil, as both plans present a panoramic reform view concerning the electricity sector. Nevertheless, Fniesh was distinctive at the level of administration when he suggested the auditing and computerization as well as the appointment of new board of directors. In addition to that, he was the only one who handled the mitigation of GHG emissions through the suggestion of ratifying the Kyoto

Table 16
Industrial electrical consumption tariff in Lebanon [29].

Seasonal duration	Hourly duration	Tariff (LL/kW h/month)
Summer duration (from April 1st till September 30)	At night (From hour 0 till hour 7)	80
	At Day (From hour 7 till hour 18:30)	112
	At Peak (From 18:30 till 21:30)	320
	At Night (From hour 21:30 till hour 23)	112
	At Night (From hour 23 till hour 24)	80
Winter duration (from October 1st till March 30)	At Night (From hour 0 till hour 7)	80
	At day (From hour 7 till hour 16:30)	112
	At Peak (From 16:30 till 20:30)	320
	At Night (From hour 20:30 till hour 23)	112
	At Night (From hour 23 till hour 24)	80

Table 17
Summary of electricity reform plans ([30], [45] and [46]).

Recommendations	Plan of Minister Mohammad Fneish	Plan of Minister Alain Tabourian	Plan of Minister Jebran Bassil
Generation			
Use NG/LNG for operating Deir-Ammar/Zahrani plants	⊠		⊠
Rehabilitate or upgrade existing plants		⊠	⊠
Build new public CCGT plants	⊠	⊠	⊠
Build new IPP-CCGT plants	⊠		⊠
Build new coal power plants		⊠	
Convert/build most power plants on natural gas	⊠		⊠
Install generators for the short term		⊠	⊠
Diversify energy sources		⊠	⊠
Build new capacities in the field of renewable energy	⊠		⊠
Allow private generation	⊠		⊠
Build new public or private hydro power plants			⊠
Build new IPP-wind power plants (private sector)			⊠
Build new “waste to energy” power plants			⊠
Conduct pre-feasibility studies on Photovoltaic (PV) farms			⊠
Build a gas pipeline along the coast			⊠
Build LNG marine station(s)	⊠		⊠
Transmission			
Complete the 220 kV network	⊠		⊠
Complete the 400 kV Ksara station	⊠		⊠
Establish the Electricity National Control left	⊠		⊠
Build regional substations			⊠
Distribution			
Implement Automatic Meter Reading (AMR) schemes or remote control meters	⊠		⊠
Encourage the private sector to invest in and develop the distribution networks	⊠		⊠
Administration and finance			
Increase the human resource capacity	⊠		⊠
Activate the financial and administrative computerization	⊠		
Accounting and financial auditing	⊠		
Energy auditing			⊠
Appoint a new board of directors	⊠		
Corporatization of EDL	⊠		⊠
Increase the tariff			⊠
Implement Time Of Use (TOU) tariffs			⊠
Legislation			
Amend the Law 462	⊠		⊠
Adopt an energy conservation law			⊠
Resolve the problems with the current concessions			⊠
Ratify the Kyoto protocol	⊠		
Adopt a Law that encourages all forms of public private partnership at the level of generation			⊠
Energy efficiency			
Encourage the adoption of solar thermal energy (SWH)	⊠		⊠
Encourage the use of compact fluorescent Lamp			⊠
Encourage the use of energy saving public lighting			⊠

protocol. On the other hand, Bassil provided detailed suggestions at the level of generation and recommended the installation of a gas pipeline all along the coast. In addition, he was very distinctive at the level of energy efficiency by encouraging the use of residential Compact Fluorescent Lamps and energy saving public lighting. Moreover, he suggested tariff increase and adjustment and dared to display the problems of concessions uncaring all political concerns. As for the plan of minister Tabourian, it focused only on the electricity generation sector and suggested a distinctive recommendation represented in building new coal power plants. In brief, it can be noticed that the plan of 2006 was a basis of the more effective and comprehensive one of 2010, while the plan of 2008 mainly highlighted on the electricity generation issue.

6. Optimization of cost and pollution for electricity generation in Lebanon

The predominant rates of annual electricity demand growth found in the literature vary between 2.5% and 8% [51]. Adopting an average annual demand growth of 5% between the base year 2009 and the year 2027, the demand is supposed to reach 36,100 GW h (Fig. 18).

Based on EDL generated electrical energy in 2009 (10,406 GW h) [30] and aiming to set a 5-year generation master plan that could meet all the demand until the year 2027 (36,100 GW h), EDL is assumed to preserve the amount of electricity generated in 2009 and be able to generate additional 25,700 GW h by the end of 2016. To achieve this, the following 10 options are studied:

1) Construction of new CCGT power plants.
2) Rehabilitation of the existing plants in Zouk and Jieh.
3) Upgrading Deir-Ammar and Zahrani CCGT power plants.
4) Adding CC to the OCGT plants in Baalbek and Tyre.
5) Construction of wind farms for electricity generation.
6) Construction of MSW power plants.
7) Construction of new hydro power plants.
8) Construction of coal fired IGCC.
9) Construction of solar-PV power plants.
10) Construction of solar thermal, PT power plants.

Table 18 illustrates the technical data for different power plant options stated above and Table 19 shows the net calorific values, costs and greenhouse gas (GHG) emissions of different fuels used in this study.

Solar-PV and solar-thermal for electricity generation are subjected to rapid technical evolution as well as their current levelized costs (Table 18) are not competitive and thus, they will be disregarded in this optimization problem.

An optimization problem is formulated in order to find the needed installation capacity (x_i) from each power option corresponding to the optimum cost and pollution. It is stated as follows:

First, define the function "f1" for cost and "f2" for pollution as follow:

$$f1 = \Sigma(\text{levelized cost} \times CF \times 8760 \times t) \times x_i \quad (1)$$

where x_i: installed capacity of each power option; $1 < i < 8$.

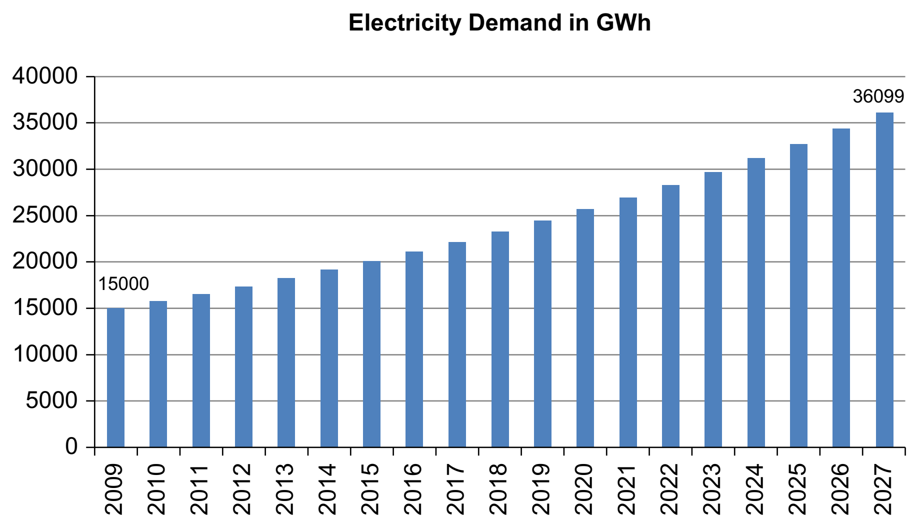

Fig. 18. Forecast of the electricity demand up to 2027 with 5% growth per year.

Table 18
Technical data (data source: 1. [30], 2. [3], 3. [52], 4. [53], 5. [54], 6. [55], 7. [56], 8. [57], 9. [58], 10. [59], 11. [60], 12. [34], 13. [61], 14. [62], 15. [63], 16. [19], 17. [64], 18. [65], 19. [66] and 20. [44]).

Power source options	Investment cost (M$/MW)	Economic Life cycle (years)	Fixed O&M cost ($/MW)	Variable O&M cost ($/MW h)	Capacity could be added (MW)	grams of CO_{2eq}/ kW $h_{\text{-el}}$	Capacity factor (%)	Efficiency (%)	Construction time (years)	Levelized cost ($/MW h/year)
1 (CCGT)	1.25[1]	25[17,19]	11,936[5]	2.05[5]	open	–	85[5]	48[8,9]	2.5[17]	62.3 (NG) 203.3 (GO)
2 (ST) Zouk Jieh	0.23[1]	10[12]	11,936	2.05	70[1] 30[1]	–	70[20]	38[8] 33[8]	0.5	159.4 182
3 (CCGT)	0.114[1]	25[17,19]	11,936[5]	2.05[5]	75[1]	–	85[5]	48[8]	0.5	45.5 (NG) 186 (GO)
4 (CCGT)	0.62[1]	25[17,19]	11,936[5]	2.05[5]	70[1]	–	85[5]	48[8]	0.5	52.9 (NG) 194 (GO)
5 (WT)	1.95[1]	20[19]	30,921[5]	0	250[2]	13[3]	34[5]	35[9]	2[19]	87.3
6 (MSW)	1.9[1]	20[18,19]	100,000[18]*		107	60[4]	68[6]	22[9,16]	2[1,16,19]	94.25
7 (Hydro)	4[7]	30[7]	35,000[7]	0	205	4[3]	50[7]	95[9]	5[7]	104.8
8 (Coal IGCC)	3.7[13]	25[13,19]	39,459[5]	2.98[5]	open	750[10,13]	85[5,13]	45[10]	4[10,13]	81.8
9 (Solar-PV)	5[15]	25[15]	11,926[5]	0	NA	105[3]	21[5]	16[15]	NA	305.9
10 (Solar-PT)	5[14]	40[14]	57,941[5]	0	NA	90[11]	31[5]	14[14]	NA	209.6

* Includes fixed and variable O&M costs in $/MW/year; NA: Not available.

The levelized cost is a worldwide method used in the cost comparison studies of different power plants. The details of this method can be found in [69].

$$f2 = \Sigma(tCO_{2eq}/MW\,h \times CF \times 8760 \times t) \times x_i \quad (2)$$

Second, define the function "g" which combines both functions above:

$$g = \alpha \times (f1/\text{maxcost}) + (1-\alpha) \times (f2/\text{maxpollution}) \quad (3)$$

where $0 < \alpha < 1$

Table 19
Characteristics of fuels (data source: 1. [41], 2. [58], 3. [42], 4. [67], 5. [34], 6. [68]).

Fuel type	NCV (MJ/kg)	Cost ($/ton)	GHG (tCO_{2eq}/ton)
HFO	40.6[1]	640[3]	3.7204[6]
GO	42.5[1]	1027[3]	3.7221[6]
Hard coal	34.1[2]	80[4]	–
NG	37.9[2*]	5.65[5**]	60.96[6***]

* MJ/m^3.
** $/MMBTU.
*** gCO_{2eq}/MJ.

Three scenarios are studied:

1. All CCGT plants operate using gas oil except the new ones which use NG.
2. All CCGT plants operate using GO.
3. All CCGT operate using NG.

Matlab software [70] was used to solve the suggested optimization problem. The results of the suggested scenarios are illustrated in Figs. 19–21. The intersection between normalized cost and normalized pollution curves is considered to be the optimum solution.

The overall investment capital cost of the first scenario is 4677.5 M$. Using this scenario, an added pollution of 11.6 $MtCO_{2eq}$ will be obtained in 2027 due to the installed new capacities.

The investment cost of the second scenario is 5312.75 M$. Using this scenario, an added pollution of 15.4 $MtCO_{2eq}$ will be obtained in 2027 due to the installed new capacities.

The investment cost of the third scenario is 4548.2 M$. Using this scenario, an added pollution of 11.6 $MtCO_{2eq}$ will be obtained in 2027 due to the installed new capacities. Noting that, in this case, the overall GHG emissions is decreased further more compared to

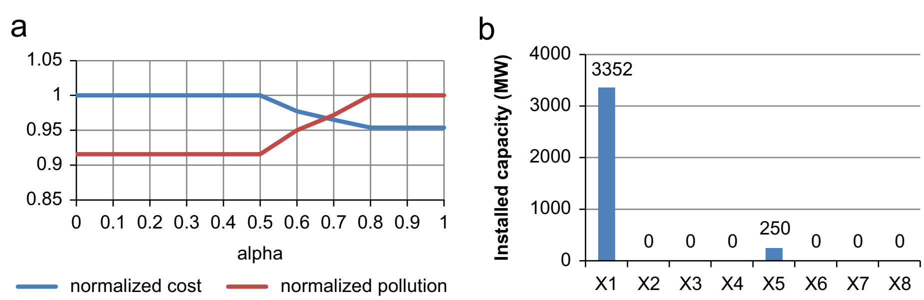

Fig. 19. (a) Variation of normalized cost and normalized GHG emissions in function of the weighting factor (alpha); (b) installed capacity to be added from different power options.

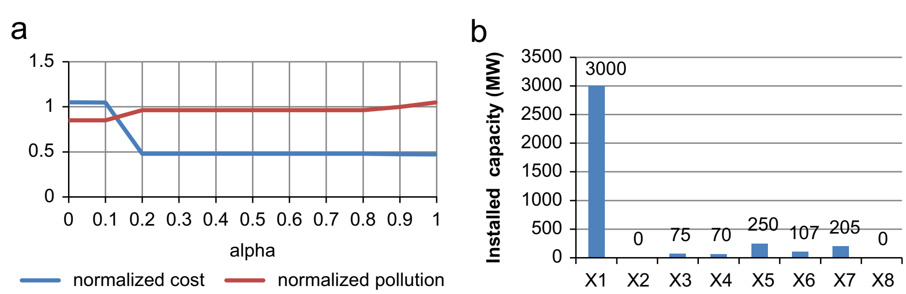

Fig. 20. (a) Variation of normalized cost and normalized GHG emissions in function of the weighting factor (alpha); (b) installed capacity to be added from different power options.

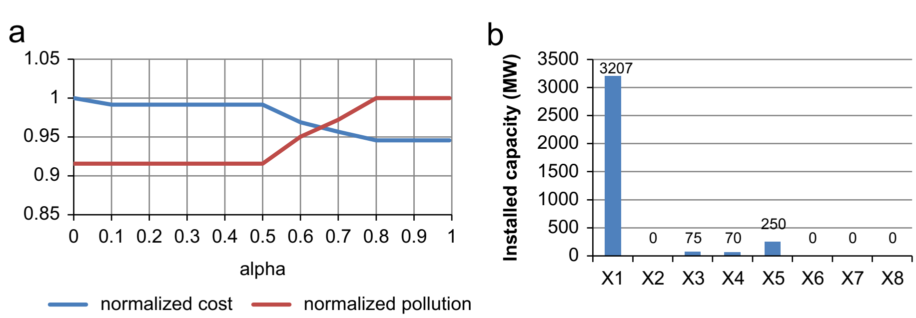

Fig. 21. (a) Variation of normalized cost and normalized GHG emissions in function of the weighting factor (alpha); (b) installed capacity to be added from different power options.

the preceding scenarios as the emissions of the existing CCGT plants will be reduced due to the use of NG instead of GO.

Based on cost and pollution optimization, it could be concluded from the above studied scenarios that the maximum potential of wind energy should be utilized. Moreover, the fossil fuel power plants (new and existing) should use natural gas as maximum as possible.

7. Electricity generation reform plan

7.1. Historical review

Several studies handled the electricity problem in Lebanon. Some of them proposed reform plans and others merely analyzed the problem and recommended certain measures.

Few articles dealt with the electricity plans at the level of supply. Chedid et al. [71] studied different scenarios at the level of pollution reduction without taking into consideration the economic analysis and concluded that mitigation is better with RE technologies than that with NG. Karaki et al. [72] studied the optimal additions of generating units; however the study was limited to conventional generating units using fossil fuel without analyzing RE technologies. El-Fadel et al. [12] studied different RE-scenarios for mitigating GHG emissions related to electricity generation in Lebanon. Wind energy was excluded in the study because the wind speed data at that time did not support its use for electricity generation. As for Biomass, gas recovery from large MSW landfills is recommended and due to the lack of such landfills, biomass energy was also excluded. Thus, only solar and hydro resources were investigated showing that 35% of the total annual GHG emitted by the electric sector could be reduced if these resources were exploited properly. Abi Said [5], in 2005, analyzed the electricity profile in Lebanon and found that the electric sector suffers from technical, administrative and financial problems. Several recommendations were concluded such as the priority to reduce technical and non-technical losses, collection of all bills, shifting to NG for thermal power plants, increasing tariffs etc. Furthermore, he stated that for an electricity reform plan to succeed, three main parties, namely: MEW, private sector as an operating partner, and regulatory body, should play their roles in the best way. Houri [73] studied several scenarios for the future of hydropower in Lebanon. The study concluded a decreasing percentage share of hydropower in the Lebanese electric generation system for all scenarios, due to the limited supply of water and increasing electricity demand. Moreover, according to the best-studied scenario, the percent share of hydropower would constitute 6.9% of the total electricity generated by 2020. The World Bank study [34] performed a detailed analysis about the Lebanese electricity sector, in which an 8-year-proposed reform plan was suggested. Based on this plan, 1500 MW of additional electrical capacity are required to meet the demand by 2015. However, this plan has an important drawback since it assumes that EDL is supposed to share about 67% of the sector, leaving the rest for informal private generation. Other drawbacks include the absence of RE investments and unextending of the capacity target beyond its time limit (2015), which means that the electricity supply is deficient again in 2016 as a result of the annual demand increase. Moreover, it proves that large gas-fired CCGT and coal-fired steam power plants are the best economic options for Lebanon contrary to CCGT using LNG or gas oil. Concerning the required tariff adjustment, four scenarios were introduced and analyzed revealing that a one-off tariff increase of 99.2% in 2010 yields the best results. Dagher and Ruble [50] examined the evolvement of the backup sector and its related CO_2 emissions in a base line scenario. They compared it to an alternative wind-RE scenario that keeps the backup generation constant. The obtained results indicated that the RE scenario cost investment is approximately half that of the base line and CO_2 emissions are less by 37% in 2025. However, this alternative scenario needs 2133 MW of wind turbines which is a very large amount knowing that the estimated wind power potential is almost 1500 MW [14] and is mostly located on top of mountains where the total investment (needed infrastructure: roads, transmission lines, etc.) may be huge and unreasonable. El-Fadel et al. [74] presented an evaluation study of the Lebanese electricity sector in terms of its sustainability. The study indicates that substantial net cost and environmental benefits can be obtained from improving the transmission and distribution networks, upgrading existing conventional plants to their design standards, and shifting to natural gas. Also, it indicates that Lebanon needs to build up 8 new, 600 MW power plants by 2030, and that renewable energy sources are competitive alternatives now. Ruble and Nader [47] presented the current challenges and the recent move towards renewable energy and energy efficiency in the Lebanese energy sector. Many policy recommendations concerning the electricity sector reform were introduced. The most important are: diversifying energy sources and suppliers, achieving the regional grid-interconnection, authorizing decentralization and privatization of electricity production, transmission and distribution, preventing theft, collecting all bills, adjusting tariffs, and legalizing renewable energy for power production. The authors concluded that a market approach based on releasing monopolization and legalizing private investments along with government setting the policy

Table 20
Proposed electricity generation reform plan.

Description	Investment (M$)	Capacity added by time						Annual savings (M$)			
		2012	2013	2014	2015	2016	2017	2013	2014	2015	2016
Rehabilitation of Zouk and Jieh	180	–	100	–	–	–	–	56	56	56	56
Upgrading of Deir-Ammar(NG) & Zahrani(GO)	108	–	75	–	–	–	–	477	477	477	477
Adding CC to Tyre and Baalbek	130	–	70	–	–	–	–	69	69	69	69
Increase the tariff by 50%	–	–	⊠	–	–	–	–	174.8	264.9	–	–
MSW	203	–	–	107	–	–	–	–	–	–	–
WT	487	–	–	250	–	–	–	–	–	–	–
New CCGT(NG)	1250	–	–	–	1000	–	–	–	–	–	–
End electricity purchasing	–	–	–	–	⊠	–	–	–	–	197.5	197.5
Increase the tariff by 30%	–	–	–	–	⊠	–	–	–	–	1328.8	1328.8
New CCGT (GO or NG)	2375	–	–	–	–	–	1900	–	–	–	–
Hydro	820	–	–	–	–	–	205	–	–	–	–
Total	5553	–	245	375	1000	–	2105	–	–	5900	–

framework would thrive the Lebanese energy sector. Dagher and Ruble [75] modeled three possible future paths for Lebanon's electricity using LEAP (Long range Energy Alternatives Planning System) software; however, the study didn't reflect a possible forecast for electricity generation as the percent-share dispatch rule was used based on the percent share of fuels in 2006. Abosedra et al. [76] investigated the dynamic causal relationship between electricity consumption and economic growth for Lebanon. Results confirmed the absence of a long-term equilibrium relationship between electricity consumption and economic growth in Lebanon but the existence of unidirectional causality running from electricity consumption to economic growth. Based on their findings, the authors present several recommendations for energy policy makers, such as prioritizing the building capacity and infrastructure development of the electric power sector, getting rid of illegal connections and encouraging research studies in the field of energy policy. However, Dagher and Yacoubian [77] concluded different results for the same study. They revealed strong evidence of a bidirectional relationship both in the short-run and in the long-run, indicating that energy is a limiting factor to economic growth in Lebanon. The authors interpret the difference in results to the application of standard causality tests without explicitly testing the "stationarity" of the employed variables by Abosedra et al. [76]. Based on their updated results, the authors advise energy policy makers to revise the latest energy policy that calls for a 5% energy conservation target. The new policy should aim at increasing the restriction of energy consumption, reducing the dependence on external energy sources by emphasizing the development of domestic energy resources (hydro, wind, solar, geothermal…) and prioritizing the relaxation of the current electrical capacity shortage. Hamdan et al. [78] assessed the latest official electrical energy policy for Lebanon, which was proposed by the MEW in 2010. The authors used the Load Modification Technique (LMT) to assess the impact of policy implementation on energy production, overall cost, technical losses and reliability. A baseline scenario for a study period extending from 2010 to 2015, with a base year 2009, was developed. The results of this scenario were compared to those obtained by the policy implementation scenario. Results revealed the effectiveness of the adopted energy policy for Lebanon. Additionally, the proposed evaluation methodology is useful as a guiding approach for power system planning appraisal for developing countries having similar deteriorating conditions in the electricity sector. Najjar et al. [79] investigated the feasibility and reliability of implementing hybrid-renewable distributed energy systems in Lebanon either by individuals or by government. This idea is supposed to reduce technical losses since the power will be generated near the grid and consequently increase the grid stability and save operating costs and environmental pollution. To achieve this goal, the authors recommend that EDL buys excess energy generated by renewable resources and that the government provides economic incentives to individuals implementing such systems.

7.2. *Proposed reform plan*

This section provides a suggested five-year reform plan for the Lebanese electricity sector at the level of generation. It is based on economic and technical data found in previous studies and on the optimization study illustrated in Section 6.

In 2009, EDL generated 10,406 GW h electrical energy [30]. The proposed five-year reform plan aims to meet all the demand until the year 2027 (36100 GW h). Assuming that EDL will preserve the generated amount of electricity in 2009, it is devoted to be able to generate additional 25,700 GW h by the end of 2016. Accordingly, the available power capacity will increase from 1650 (2010) [37] to 5375 MW (2017).

The plan is considered to start at the beginning of 2012 and all savings and added incomes compared to EDL status in the base year 2009 are calculated. Several assumptions are considered as follow:

- EDL will preserve the capability of generating the same amount of electricity produced in 2009.
- O&M costs are almost the same for existing power plants.
- 68% of the total produced electricity is billed (3% improvement from the base year 2009, assuming that EDL would reduce its non-technical losses by 3% as the case achieved during 2004–2005 [34]).
- All billed electrical energy is collected.
- The Egyptian NG could be secured for 1000 MW CCGT power plants through the Arab gas pipe line.
- The Syrian NG pipeline is ready to feed Deir-Ammar CCGT power plant.

Based on the stated assumptions as well as on the results of the second and third scenarios illustrated in Section 6, the following actions are suggested:

I. Immediate actions
   - Use of NG in Deir-Ammar CCGT power plant as it is ready to do so [80].
   - Rehabilitation of the power plants in Zouk and Jieh.
   - Upgrading Deir-Ammar and Zahrani power plants
   - Adding CC to Tyre and Baalbek power plants.

   The stated work is estimated to be achieved in six months costing about 418 M$ [30]. As a result, 245 MW will be added to the actual installed capacity which would generate 1693 GW h. Additional 1600 GW h are generated from the pre-existing power plants due to the increase of capacity factors (assuming 70% load factor for Jieh and Zouk and 85% for the others) as a result of upgrading and rehabilitation of existing plants. As a whole, EDL would be able to produce about 14800 GW h (with purchased amounts) and reduce the deficit from an expected 11 h/day to about 4 h/day in 2013.
   Additionally, the following actions are also performed immediately:
   - Start building 205 MW hydro power plants (820 M$) that are expected to be completed by the end of 2016.
   - Start building 107 MW MSW-plants (203 M$) and 250 MW WT-plants (487 M$). They are expected to be completed by the end of 2013.
   - Start building 1000 MW CCGT (NG) plants (1250 M$), which are expected to be completed by the end of 2014.

II. Additional actions
   - The great decrease in rationing, stated above, would find a valid ground for increasing the current low electricity tariff because it may motivate the Lebanese citizens to leave the low-quality private generation sector which is the actual case existing in Beirut nowadays. Accordingly, a tariff increase of about 100%.over two stages is suggested. This suggestion is based on the average cost of electricity (17.14 ¢/kW h) in 2009 [30], thus raising the overall average tariff from 9.4 ¢/kW h currently [34] to 14.1 ¢/kW h in the beginning of 2013 (~50% increase) and then to 18.3 ¢/kW h in the beginning of 2015 (~30% increase from the last tariff).
   - In 2014, Start building 1900 MW CCGT plants that could operate using either NG or GO (2375 M$) and which are expected to be completed by the end of 2016.
   - In 2015, stop purchasing electricity from Syria as the new built plants will be able to cover the entire deficit.

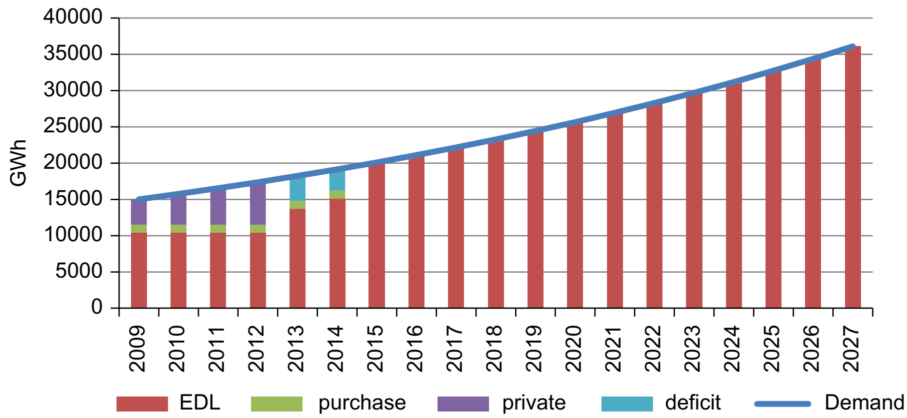

Fig. 22. Electricity generation between 2009 and 2027 according to the proposed reform plan.

The economic benefits resulting from the application of the illustrated plan are as follow:

- The overall savings achieved due to the improved efficiencies of existing plants and the use of NG in Deir-Ammar will be about 602 M$/year.
- An added net income of 174.8 M$ is expected in 2013 due to the application of the new tariff (368 M$ from the old capacity+315.8 M$ from the new capacity—509 M$ the cost of the new generated energy). As a result, the deficit is reduced by 776.8 M$ in 2013 (602 M$+174.8 M$).
- An added net income of 264.9 M$ is expected in 2014 (compared with the base year) due to the introduction of additional power plants (MSW and WT plants).
- An added net income of 1328.8 M$/year is expected in 2015 and 2016 (compared with the base year) due to the second-stage tariff increase.
- An added net income of 197.5 M$/year is expected in 2015 and 2016 (compared with the base year) due to ending of the electricity purchase from Syria.

The electricity generation reform plan is summarized in Table 20. Fig. 22 shows the electricity generation evolution between 2009 and 2027 based on the suggested plan.

8. Conclusion

This study presents a detailed review of conventional energy status in Lebanon. It reveals that the country is currently a major oil importer (~93% of TPES); despite the evidence for the existence of oil and natural gas in the Lebanese onshore and offshore. Therefore, prospecting for these resources must be a priority for the government. Moreover, a detailed review of the renewable energy potential is conducted, revealing a great potential of solar and wind energy resources, a considerable potential of MSW–biomass resource, in addition to an important annual amount of water resources that could effectively be more exploited in electricity generation. Besides, the main barriers to the development of RE sector in Lebanon are discussed all along with the recommended solutions. Furthermore, a detailed review of the unique official electricity provider "EDL" is carried out, displaying that the institution suffers huge technical (generation, transmission and distribution), administrative and financial problems. These problems are discussed separately and several recommendations are suggested. In the aim of resolving the electricity sector problem, three official reform plans have been developed by the ministry of energy and water (MEW) since 2006; however, no one was entirely established till now due to the large political conflicts. A comparison among these plans is conducted, where the results showed that the plan of 2006 was a basis of the more effective and comprehensive one of 2010, while the plan of 2008 mainly highlighted on the electricity generation issue.

Currently, electricity has become one of the social security needs and living priorities for all citizens and thus, meeting the electricity demand must be a priority for the Lebanese government. However, in the approach to meet the demand, several power source options exist. For this reason, an economical–environmental optimization of different power sources is studied such that EDL will be able to meet all the electricity demand until the year 2027, starting from EDL generation status in 2009. Three scenarios are introduced based on the fuel source of different CCGT power plants. The first scenario considers that only new CCGT use NG while the second considers that all CCGT use GO and the third considers that all CCGT use NG. The results prove that the third scenario is the best economically and environmentally followed by the first one. Additionally, It is concluded that the maximum potential of wind energy should be utilized and that fossil fuel power plants (new and existing) should utilize natural gas as maximum as possible.

Although the third scenario proved to be the best; only a part of the installed capacity of CCGT plants (~1500 MW) will be able to use NG. Thus, both the second and third scenarios are chosen as bases in formulating a new generation plan for Lebanon. This is due to the fact that securing NG for all thermal plants is currently difficult. Based on this proposition, a five-year master plan for electricity generation is modeled. This plan suggests an additional temporary solution (rehabilitation of Jieh and Zouk) that helps reducing the electrical shortage in a way that informal private generation could be abandoned starting from the second year. It also suggests an increase in the tariff by 100%, split into two stages, to make EDL able to meet its different costs. It is worth to note that the tariff increase needs a detailed analysis to decide the new effective equitable basis. This plan is quite reasonable as the savings and additional incomes (5900 M$) will be more than the investment cost (5553 M$) as well as it exceeds the trend to introduce a 12% share of renewable energy in the power sector by 2020 [30], where the share is supposed to be about 15% out of the total installed capacity before this date. The proposed plan will also assure the diversification of energy resources (NG, GO, wind, waste, hydro etc.).

Finally, Lebanon is an indebted country that depends, for the moment, on oil imports to meet its various energy needs. Seeking to reduce its debt, meet the growing energy demand and reduce the environmental pollution, an overall energy strategy should be adopted to enhance energy efficiency and renewable energy at

the level of electricity production and consumption. In addition, real efforts should be done to enhance the prospect for oil derivatives on/off-shore and before all, establishing a proper political environment is a prerequisite for such a strategy.

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